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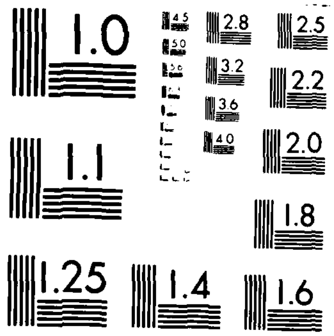
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The Pennsylvania State University

The Graduate School

Department of Architectural Engineering

The Influence of Glazing Systems on the Energy Performance of Low-Rise Commercial Buildings

A Thesis in

Architectural Engineering

by

Steven H. Wiebke

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 1985

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ABSTRACT

The impact of variations in glazing parameters on building energy consumption is examined for a typical low-rise commercial office building. The net annual effect greatly depends on a complex interaction among climatic conditions, building design features, and building operating characteristics.

The goal of this study was to segregate the energy effects of fenestration design, quantify these effects, and develop simplified analysis tools for use by building designers. As well, economic parameters were integrated in order to analyze total performance results in diverse energy regions of the country.

This study includes simulation of annual building energy performance and thermal response using the DOE-2.1A energy analysis simulation program, generating a data base for the multiple regression statistical investigations, and life-cycle cost analysis. A representative range of commercial glazing systems, through the primary parametric glazing properties (U-value,shading coefficient), was considered. A base single clear glass was compared to ten specific insulated systems for ten climatic regions throughout the United States.

Guidance was developed for effective glazing system utilization in low-rise office buildings, in terms of energy

performance and cost-effectiveness. Statistical analysis results in simplified correlation expressions among important glazing and climatic variables. These expressions permit the quantification of changes in annual energy performance trends for cooling, heating loads and peaks so that the designers can determine the implications of design options for various glazing systems.

Life-cycle cost results indicate that low-emissivity glazing systems in configurations, with and without tinted exterior lites, outperform other systems in all climates except those with exceptionally high cooling loads. For high cooling load dominated locations, high reflective metallic systems with lower shading coefficients were more efficient applications.

Key Words: glazing, climate, building energy analysis, multiple regression, life-cycle cost, cooling loads, heating loads, peaks.

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studied parameters for the glazing systems within the context of the representative weather information used. Extreme deviations, in either the glazing properties or the weather conditions, have not been validated. The issue of daylighting has not been considered in this research. Ongoing complications (Selkowitz,1982) with respect to occupant management and satisfaction, proficient design ability, glare and cost of dimming/switching systems have hampered its widespread usage. This research has not been validated for buildings with operational daylighting strategies. An economic limitation within the life-cycle cost analysis occurs when considing situations being influenced by corporate investment tax credits. This study did not consider tax credits in the economic evaluation which would probably yield linearly equivalent, however different economic results.

1.4 Contribution

This thesis makes a contribution to the building design profession by developing guidance to assess glazing performance effects upon building loads and peaks through simple algebraic expressions. It enables the user to analyze variations in parameters with their respective effect on energy requirements. Even though involved methodology is available for successfully establishing the results that glazing properties have on loading, there is no simplistic

so that the cost effectiveness of the systems can be determined on a life-cycle cost basis (Ruegg,1980). The product of this research is proposed for use by building designers to act as guidance in the analysis of effective glazing systems, for both new and retrofit applications, subject to the limitations described in a subsequent section. The research will be accomplished in the following manner:

1) Determine requirements for building model and representative climatic locations.
2) Evaluate current glazing performance criteria and available commercial systems.
3) Utilize multiple regression techniques in predicting glazing performance effect on building loads and peaks.
4) Employ life-cycle cost analysis procedures in determining the most efficient system for desired use.

1.3 Limitations

The strategies developed in this research are limited to the assessment of glazing parameters for low-rise commercial buildings with similar aperture ratios and operating characteristics. Other building types with significant alterations to the analyzed conditions, could result in contrary results. The regression analysis is limited to the

allow for simplified modelling and subsequent numerous, less expensive computer runs. These results are derived from identical geometric zones, constrained thermal transfers and several external surfaces modelled adiabatically. The universal nature of this type of study, applicable to a wide range of building types, carries through to the occupancy characteristics and internal loading assignments. Solar glazing film has been studied (Treado,et al.,1983b) through a specific building type for several climatic locations, revealing performance and economic results for retrofit films on glazing systems. There is seemingly little information available concerning net annual energy performance of specific glazing systems, especially since the development of low-emissivity coatings for distinctive locations in the country.

1.2 Thesis Objectives

This research focuses on the analysis of the impact of various glazing systems on the building energy requirements for a typical low-rise commercial office building. A central goal is to develop graphic results from sensitivity studies to enable designers to evaluate indicated effects on energy performance. A simple and precise method to determine glazing parameter effects on building loads and peaks will be developed. System cost information will be integrated with current energy prices and annual performance

low-emissivity coatings have reduced impedance to a level where R-4 systems are now commercially available, equaling the insulating ability of many pre-energy crisis exterior wall systems. Current research (Selkowitz and Lampert,1983) in optical switching materials for glazing systems including chromogenic, electrochromic, photochromic, thermochromic, physio-optic and electro-optic switching mechanisms, as well as transparent aerogels and low-convection gas fills, holds much promise for the future of fenestration efficiency.

Although the outlook on developing research is encouraging, this study deals with current advanced glazing systems available for commercial buildings. Past studies in glazing performance have taken a number of diverse approaches. Recent parametric analyses in building energy studies (Sullivan,et al.,1983) have addressed a minimal number of optional glazing parameters in pursuit of a general regression expression to assess energy performance variables. This type of analysis assumes selective parameters and omits the full range of specific qualities available, which do vary considerably. Other investigations (Treado,et al.,1983a) conduct fenestration energy analyses for a single geographic location, limiting the applicability of the results to that climatic area. The building module concept used in many recent parametric studies (Johnson,et al.,1983) stresses a prototypical module single floor in a multi-story office building. This strategy is apparently to

to a temporary imbalance in supply and demand. Costs will again begin to rise as inevitable dwindling natural resource reserves create a reduced supply with higher prices. Once again energy performance in building elements will become a primary issue for designers.

The thermal response of fenestration devices results from a complex interrelationship among glazing properties, orientation, building operations, and climatic conditions. They traditionally provide little resistance to heat transfer between the building exterior and the ambient enviornment. A comparison of the thermal impedance (R-value) of a normal double-glazed unit, which is between 1.0 and 3.0, to the thermal impedance of most exterior walls, which is between 10.0 and 20.0, suggests that most windows are thermal leaks in the building shell. In addition to the impedance parameter, the radiant energy admitted by glazing systems can have a significant impact on its cooling load. It can account for as much as 60 percent of the total cooling load (Yellott,1963) in commercial buildings located in southern climatic zones. Attempted solutions to the solar gain have been partially successful with integration of architectural control strategies such as draperies, screens, shades, louvers and films. Good results have also been obtained by using tinted and reflective glazing to significantly reduce gains in commercial applications. Recent developments of systems with selective transmittance

Chapter 1

INTRODUCTION

1.1 Background

The use of building aperture control devices has been a common practice since their original integration within the temple architecture of ancient Egypt. At that stage their purpose was primarily simple daylighting, confined to small openings or slits in the walls. After that, glazing was sparingly used until its emergence as a significant building material in the creation of the elaborate Gothic cathedrals in Europe. Architecture evolved with glazing as a primary design element, until recent energy issues raised concern over its past limitless quality and quantity.

Since the energy crisis in the early seventies, fenestration design in buildings has fluctuated in practice. Dramatically rising fuel prices in the middle seventies stifled designers' aesthetic creativity. The one-time predominantly artistic design element became a specific performance concern in an age of soaring energy costs. Major conservation efforts in the late seventies and up to the present, augmented by accomplishments in building design and operations, have solved many of the dire issues of the early seventies. Fortunately design professionals have had the foresight not to return to earlier practices in fenestration design. The situation with world energy prices is only due

respect for their lifelong support of my efforts. And to my children, Jennifer and Brett, who unknowingly to them have given me inspiration beyond explanation. But to my wife Terri, who means more to me than she could ever imagine, I owe nothing short of everything. Her dynamic ability to strive for perfection with our children, without a husband for these past months, has provided me with a constant source of motivation and enthusiasm.

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My greatest admiration and appreciation are reserved for the people who have made this work possible: my family. To my parents, Henry and Eileen, I convey my utmost love and

Solar radiation: the electromagnetic energy from the sun segregated in the ultraviolet, visible and near infrared sectors of the spectrum.

Standard deviation: the statistical square root of the variance; quantity used in indicating the accuracy of a predictor equation.

Thermal transmittance: otherwise referred to as the U-value, it is the time rate of heat flow per unit area, including its boundary films, divided by the difference between the fluid temperature on either side of the body.

Transmittance: the capacity of a material to transmit radiant energy; the ratio of the radiant flux transmitted through a body to the amount incident upon it.

Life-cycle cost: method of economic evaluation which takes into account all relevant costs of a building design, system, component, material, or practice over a given period of time, adjusting for differences in the timing of those costs.

Load: the rate at which heat must be added or extracted from a space to maintain a desired room condition.

Present value: the time equivalent value of past, present or future costs as of the beginning of the life-cycle cost study period.

Reflectance: the ratio of the total radiant flux reflected by a surface to the total incident to the surface.

Regression: a statistical analysis procedure in which relationships between variables are established mathematically using a least-squares approach; used to predict a dependent variable from independent variable relationships.

Residual: the errors made in predicting a value, from the actual observed value by use of the regression equation.

Shading coefficient: the ratio of solar heat gain for a particular fenestration to the gain for a reference double-strength single glazing.

Shading factor: the ratio of solar heat gain to the incident solar radiation level.

Solar heat gain: the gain resulting from incident solar radiation including both absorbed energy from convection and radiation, and from transmittance.

GLOSSARY

Absorptance: the capacity of a material to absorb radiant energy; the ratio of the radiant flux absorbed by a body to that incident upon it.

British thermal unit: the heat required to raise the temperature of a pound of water from $59^{o}F$ to $60^{o}F$.

Conductance: the time rate of heat flow through a body from one of its bounding surfaces to the other for a unit temperature difference between the two surfaces, under steady state conditions.

Convection: transfer of heat by movement of a mass of fluid.

Degree day: for any one day, when the mean temperature varies from $65^{o}F$ there exist as many degree days as there are Fahrenheit degrees difference in temperature between the mean temperature for the day and $65^{o}F$.

Emittance: the capacity of a material to emit radiant energy; the ratio of the total radiant flux emitted by a body to that emitted by an ideal black body at the same temperature.

Infrared radiation: energy emitted at the surface of a body which has been thermally excited.

Internal load: any load due to sources contained in the space, such as equipment, lighting or people.

GLDC(LE)	high reflective gold outside-both clear lites
SILC(LE)	high reflective silver out-both clear lites
u	unit of wavelength measurement(micron)
τ	transmittance of solar radiation
α	absorbtance of solar radiation
ρ	reflectance of solar radiation
I	absorbed solar radiation
h	air conductance coefficient
t	temperature
q	heat flux
F	solar heat gain coefficient
R^2	statistical coefficient of determination
A	Y intercept value
B	regression coefficient
e	random error off regression fit
Y'	Y-hat or predicted value of Y
X	independent variable
Y	dependent variable
T-ratio	statistical test for variable significance

LIST OF SYMBOLS

CLLD	total cooling energy(MBtu/yr/ft^2)
CLPK	maximum cooling load(KBtu/hr/ft^2)
HTLD	total heating energy(MBtu/yr/ft^2)
HTPK	maximum heating load(KBtu/hr/ft^2)
UVALSUM	thermal transmittance-U (Btu/Hr/Ft^2)
SHADCOEF	shading coefficient-SC (unitless)
LAT/DEG	latitude(degree)
WINTEMP	winter 97.5% design temperature(^{o}F)
SUMTEMP	summer 2.5% design temperature(^{o}F)
HDD/B65	heating degree days(base 65)(^{o}F)(day)
CDD/B65	cooling degree days(base 65)(^{o}F)(day)
MDSR/Jan	mean daily solar radiation january(langleys)
MDSR/Jul	mean daily solar radiation july(langleys)
Btu	British thermal unit
MBtu	one million Btu
KBtu	one thousand Btu
SING(LS)	single lite clear glass
DBLG(LS)	two clear glass lites
TNTC(LE)	tinted outside lite-clear inside lite
LOEC(LE)	clear outside lite-low emissivity inside lite
LOET(NT)	tinted outside lite-low emissivity inside lite
HTMC(LE)	low emissivity film between two clear lites
HTMT(NT)	low emissivity film between tinted-clear lites
LORT(NT)	low reflective tinted out-clear inside lite
HIRT(NT)	high reflective tinted out-clear inside lite

procedure to accurately determine them for rapid assessment. The economic evaluations permit accurate appraisal of current glazing systems and their performance throughout several areas in the United States. The methodology and conclusions made in this research offer a contribution to the building design professions through optimization in glazing performance strategies, resulting in conservation of energy, resources and economic efficiency.

1.5 Overview

This thesis is organized into five separate sections following this introduction. The second chapter discusses the evaluation of the energy analysis simulation, building model, and representative weather locations. Chapter 3 deals with glazing properties and the systems that were parameterized. The multiple regression analysis for individual cities and integrated climatic data is covered in Chapter 4. In Chapter 5 the preceding data base is further analyzed with energy and specific system costs in performing the life-cycle cost analysis. Finally, in Chapter 6, conclusions and recommendations are offered for prospective research.

Chapter 2

THE BUILDING SIMULATION

2.1 Computation Analysis

Current methodology in assessing the energy performance of a building ranges from generalized rules of thumb, aquired over years of experience, to complex digital simulation programs. The data base generated, for the regression and cost analysis in this research, was accomplished with the Department of Energy (DOE) 2.1a version computer program (U.S. Department of Energy,1979). This procedure was developed by Lawrence Berkeley Laboratory and Los Alamos Scientific Laboratory in the late seventies to enable building designers to more accurately evaluate the many interrelating energy flow variables that are present in all building types. DOE 2.1a utilizes sophisticated hour-by-hour dynamic, rather than steady-state, calculation techniques in allowing for more accurate thermal lag analysis in the building shell. It calculates building loads using algorithms based on current American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) weighting factor procedures. Heat transfer components are calculated by evaluating effects of location, meteorological data, and shading upon the building shell. The gains and losses for significant building components are then evaluated, individually, for each hour in the year

(8760 hours). Infiltration and internal loading are also similarly analyzed and included in the final product.

The use of this degree of precision is not without some potential disadvantages. The time required for the complex modelling involved can be prohibitive for many situations where such detail is not essential. The programming input for this research consisted of 317 lines of control language and building descriptive code. Countless hours were absorbed in penetrating the methodology, compiling the input data, and executing the over 110 runs associated with this study. Economically, the cost of the modelling labor and computation time can be a drawback for prospective users. On a commercial scale, computer costs of $60.00 to $100.00 per run, for medium complexity full simulations, are not uncommon. The need for this level of accuracy must be appraised over the additional costs and time incurred.

2.2 Building Model

In order to simulate realistic conditions for the study, several representative building types were evaluated for consideration. The selection of the low-rise commercial building type was a result of the significant ratio of existing and new constructed buildings that are of this design. Specific choice of the building was made after thorough examination of representative facilities with varying qualities. Compatability with typical building

specifications in envelope performance, aperture ratio, and materials used was assessed. Operating schedules and internal load characteristics were also evaluated.

The actual building used in this research is a detached, two-story commercial office building built in 1981 and located in State College, Pennsylvania. It is approximately 236 feet long, 185 feet wide and 30 feet in height. The total gross floor area is approximately 50,000 ft^2 . Specific model characteristics are illustrated in Appendix A. The main level utilizes a traditional perimeter office plan with a central core area including restrooms, dining area and a computation center. Appendix A details this layout. All fenestration orientations exhibit essentially the same aperture ratio of 46 percent, equally weighted on all four sides, representing acceptable input for the study. Occupancy patterns, equipment use, lighting schedules, and temperature controls were aquired after obtaining the construction drawings and conducting an on-site investigation with the facility manager. These traits were also used as input to the model. Actually, most internal load schedules were quite similar with the variables used in the popular Standard Evaluation Technique (SET) when they were compared (Fleming and Associates,1981). Computational equipment was segregated from the traditional occupant utilized equipment and put on its own schedule.

2.3 Weather Data Considerations

Climatic locations were assessed in order to provide the study with a representative selection of useable sites. The primary parametrics of glazing, the effects of thermal impedance, and of radiant gain were used to single out locations in an attempt to test the ranges of the parameters thoroughly. Actual climatic variables input for DOE 2.1a are shown in Table 1. Recent work by Willmott and Vernon of the University of Deleware has analyzed meteorological patterns with insolation levels together (Schwoegler and McClintock,1981) to create climatic zones throughout the United States representative of the correlations. Test cities for this research, as illustrated in Figure 1, integrate these zones with locations in expectedly diverse thermal ranges. The result depicts a geographical range of ten cities, each representative of its own individual climatic conditions. Generalized climatic conditions are described in Table 2 for the specific cities.

Once the sites were selected, the individual weather data files were created from National Oceanic and Atmospheric Administration (NOAA) Test Reference Year (TRY) tapes and stored on disk (National Climatic Center,1976). TRY data consists of a specific year of hourly weather data chosen as a typical representation over 27 years of record with the National Weather Service. Table 3 shows the specific years of data with their respective altitudes for the test cities.

In this analysis, the TRY data represents an accurate collection of climatic variables well suited for the type of comparative study being accomplished. Limitations of this strategy include questionable results if analyzing specific energy performance characteristics over long periods of time.

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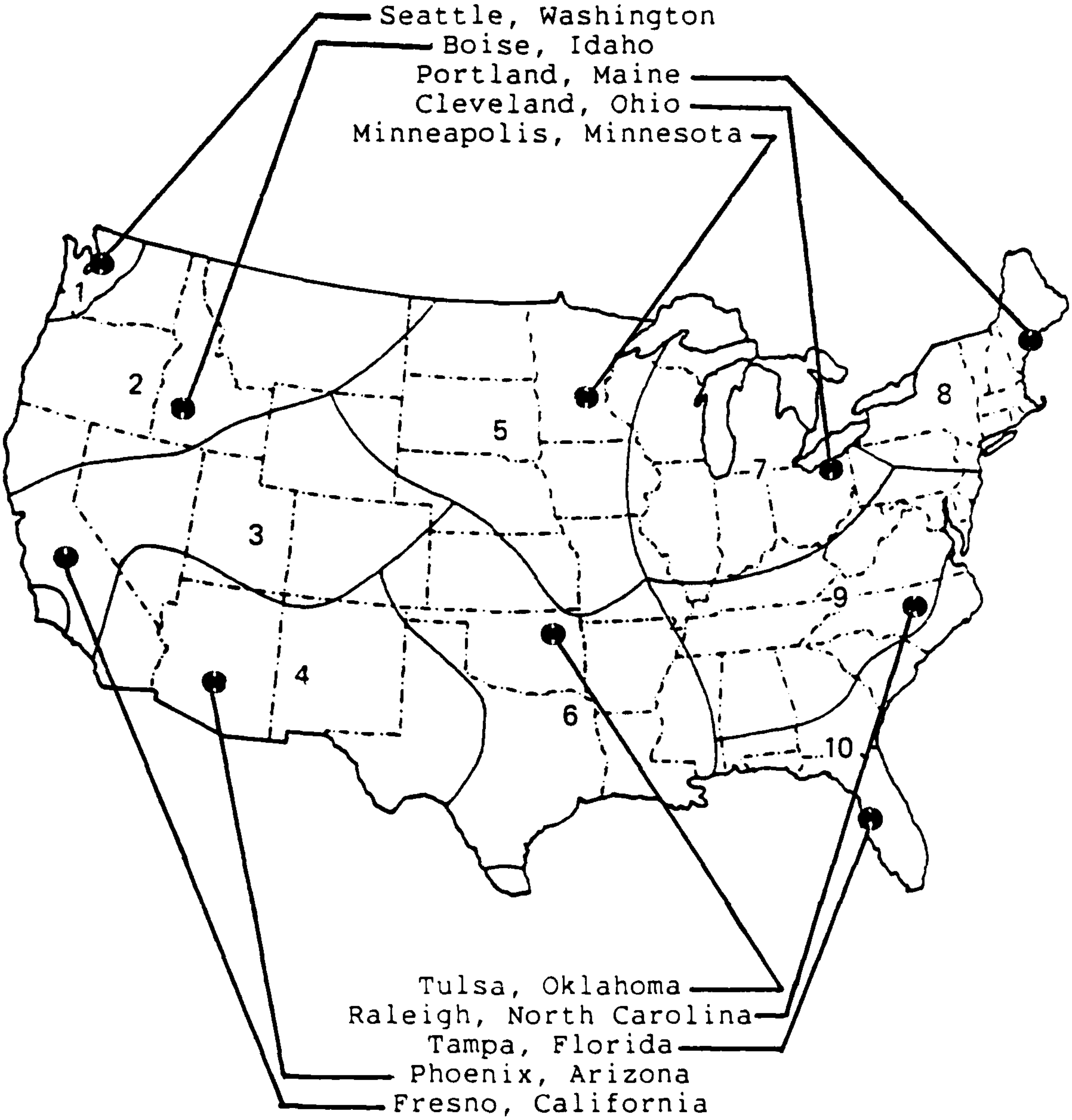

Figure 1: Location of Test Cities. Research test cities integrated with Willmott & Vernon insolation climatic zones.

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Table 1: TRY Variables Required for DOE 2.1a Input

Drybulb Temperature	Wind Direction
Wetbulb Temperature	Wind Speed
Atmospheric Pressure	Cloud Amount
Clearness Number	Cloud Type
Ground Temperature	Latitude
Site Time Zone	Longitude

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Table 2: General Climatic Patterns for Test Cities

City	Pattern
****	*******
Seattle	Prolonged cloudiness during winter, relatively high summer insolation.
Boise	Moderate winter radiation, significant summer insolation.
Fresno	Moderate seasonal insolation variation, both summer and winter.
Phoenix	Minimum insolation variation throughout seasons, high summer & winter levels.
Minneapolis	Significant overcast year-round, summer insolation spikes.
Tulsa	Moderate winter insolation, moist air reduces summer insolation levels.
Cleveland	Significant overcast in winter months, reduced summer levels.
Portland	Moderate insolation throughout entire year.
Raleigh	Moderate winter levels, reduced summer due to humidity moisture.
Tampa	High radiation area, summer varies due to moist-pollution laden air.

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Table 3: Year of Data and Altitude Used for TRY Test Cities

City	Year	Altitude
****	****	********
Tampa	1953	19
Seattle	1960	386
Raleigh	1965	19
Portland	1965	61
Minneapolis	1970	822
Fresno	1951	326
Cleveland	1969	777
Boise	1966	2842
Phoenix	1951	1117
Tulsa	1973	650

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Chapter 3

GLAZING PERFORMANCE AND SYSTEM CHARACTERISTICS

3.1 Solar Optical Properties

Solar energy is distributed to the earth in primarily three spectral components; ultraviolet,visible and near infrared. The invisible ultraviolet light makes up about 9 percent of the total solar energy spectrum and is encompassed in a wavelength region of 0.29 to 0.40 μm. Ultraviolet radiation fortunately is significantly reduced through the atmosphere and further lessened while transmitting through glass. Remaining quantities are responsible for the deterioration of fabrics, furniture and similar interior materials. The visible light contains 38 percent of the spectrum and exists in the 0.40 to 0.70 μm range. The ability to usefully capture this wavelength, daylighting, can reduce lighting load and commensurate electrical costs if properly designed. The spectral component that is the greatest concern to commercial, interior loaded applications, is the near infrared region. It lies in the 0.7 to 3.5 μm range with a significant 53 percent of the solar radiation we receive. The ability to selectively transmit portions of this range depends on the internal load requirements of the building. Internally load-dominated buildings would generally need to exclude this gain for much of the year, in most climates. Conversely,

residential skin-loaded buildings would normally welcome this additional heat source to their energy requirements. Outside this near infrared wavelength is the far infrared region, which is the emitted thermal energy from objects after absorbing the shorter wavelengthed energy. Further analysis of the recent glazing evolutions, addressing this area of the spectrum, will be covered in subsequent sections of this chapter.

The basic optical properties of glass are the reflectance(ρ), absorptance(α) and the transmittance(τ) of radiant energy relative to that material. In calculating the solar flux through the glazing system, the overall transmittance and absorptance of each layer as a function of the angle of incidence must be considered (Rubin,1982). In analyzing the portion of gain entering a space, the transmittance quantity is required. To compensate for the diffuse radiation through the atmosphere and reflected from the surrounding surfaces, a hemispherical average transmittance value is used. The gain analysis also considers the absorptance component due to the degree of near infrared energy that is absorbed, reradiated and convected to the space. A double glazed system would also assess the absorptance at each layer, accounting for the varying absorption quantities at different insulating points within. The basic optical relationship between these values is indicated by:

$$\rho + \alpha + \tau = 1 \tag{3.1}$$

3.2 Heat Transfer

Basic heat transfer through glazing systems is comprised of the radiant gain transmitted through the unit and the transfer that is convected/radiated between the glass and the internal space. Understanding that DOE 2.1a calculates the heat transfer components iteratively within the program, it is important to analyze the process in which the solutions are derived. The two general components that make up the transfer mechanism are the incident solar radiation and the temperatuie differential between inside and outside conditions. Isolating the thermal and solar qualities for simplified analysis yields two basic parameters. One, the U-value, or overall thermal transmittance coefficient, relates to the ratio of thermal gains or losses to the temperature differentials between the inside and outside conditions. Second, representing the ratio of the radiant gain of the actual glazing system to the gain for a ASHRAE reference single glass, is the shading coefficient. Both of these are directly related to the basic solar optical properties of glass, as well as to the emittance of the material itself.

The ability of a glazing system to transfer energy is a function of the solar gain penetrating the glass and of the temperature differences between the inside and outside

conditions. Assuming differing temperatures and a degree of irradiation striking the glass, heat transfer occurs between the glass and the surrounding enviornments. ASHRAE(1981) describes the absorbed inward radiation and convection gain from the inner surface of double glazed systems as:

$$q_{RCi} = U\ [\alpha I_o\ /h_o + \alpha I_i(1/h_o + 1/h_s) + (t_o - t_i)] \tag{3.2}$$

Where U = the overall thermal conductance

αI_o = solar radiation absorbed by outdoor glass

αI_i = solar radiation absorbed by indoor glass

h_o = outside surface coefficient

h_i = combined air space coefficient

t_o

$-t_i$ = temperature differential

Further investigation into the calculation of the radiant and thermal gains reveals a heat balance analysis for the glazing material. The heat balance between sunlit glazing and the temperature differentials in the surrounding enviornment is illustrated by ASHRAE(1981) in the following equation:

$$I_t + U(t_o - t_i) = q_R + q_S + q_T + q_{RCo} + q_{RCi} \tag{3.3}$$

Where I_t = solar radiation intensity

U = glazing thermal transmittance

T_o = outside temperature

T_i = inside temperature

q_R = heat reflected by the glass

q_S = heat stored by the glass

q_T = heat transmitted by the glass

q_{RCo} = rate of heat flux outward (radiation

q_{RCi} = rate of heat flux inward & convection)

The heat storage term is traditionally insignificant and can be omitted. The degree of thermal rejection to the outside is the sum of the reflected heat and the combined heat flux outward term. The inward gain is therefore represented by the inward flux and the basic transmittance terms.

At any point in time the instantaneous rate of energy flow through a glazing system is directly related to the difference between the thermal losses due to conduction, convection and far infrared radiation, and the heat gain due to solar radiation. For double glazing systems this is accomplished by the following ASHRAE procedure:

$$q_A = F(I_t) + U(t_o - t_i) \qquad (3.4)$$

Where q_A = instantaneous rate of heat flow through glazing system

F = solar heat gain coefficient

I_t = solar radiation incident on glass

U = overall heat transfer coefficient

T_o = outdoor temperature

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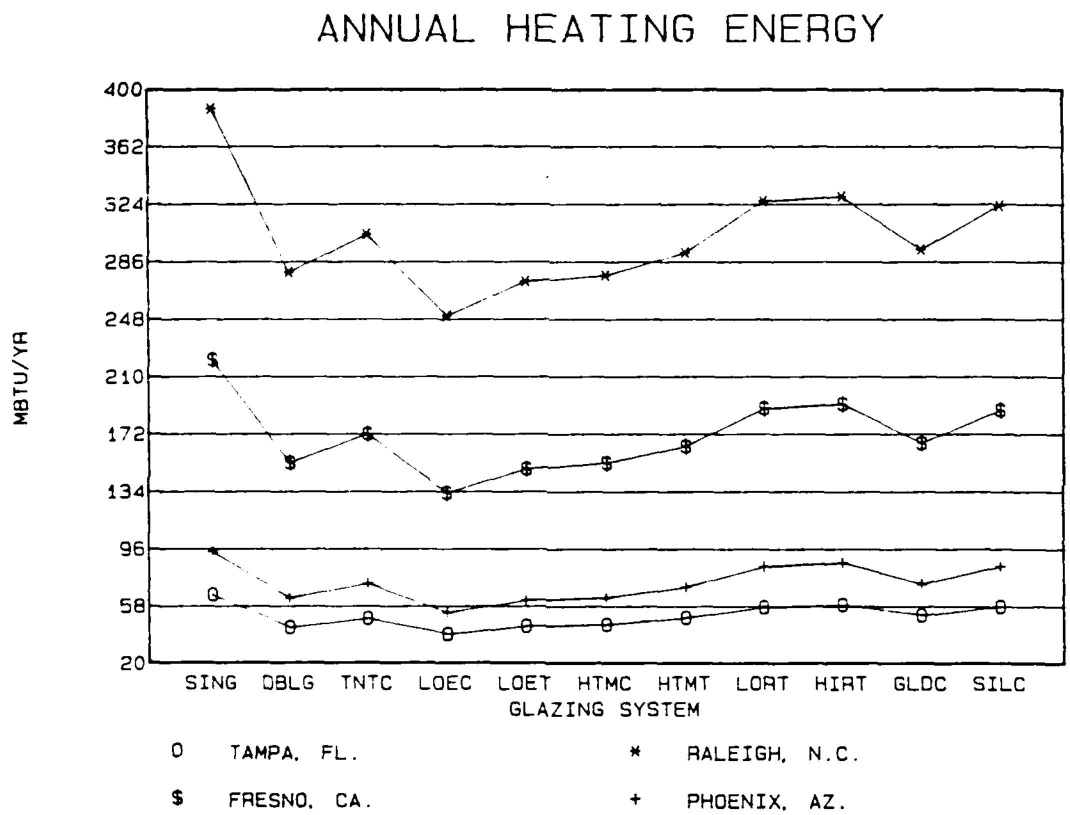

Figure 9: Annual Heating Energy for Tampa, Fresno, Phoenix and Raleigh. Refer to List of Symbols for acronym definitions.

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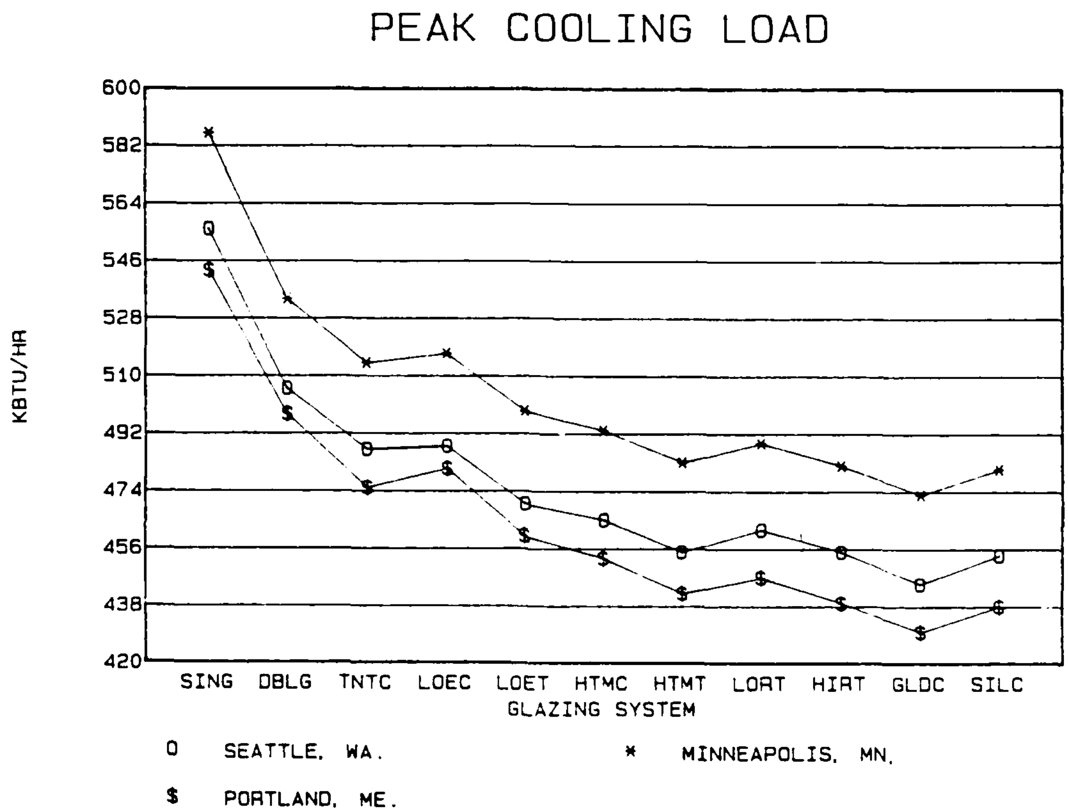

Figure 8: Peak Cooling Load for Seattle, Portland and Minneapolis. Refer to List of Symbols for acronym definitions.

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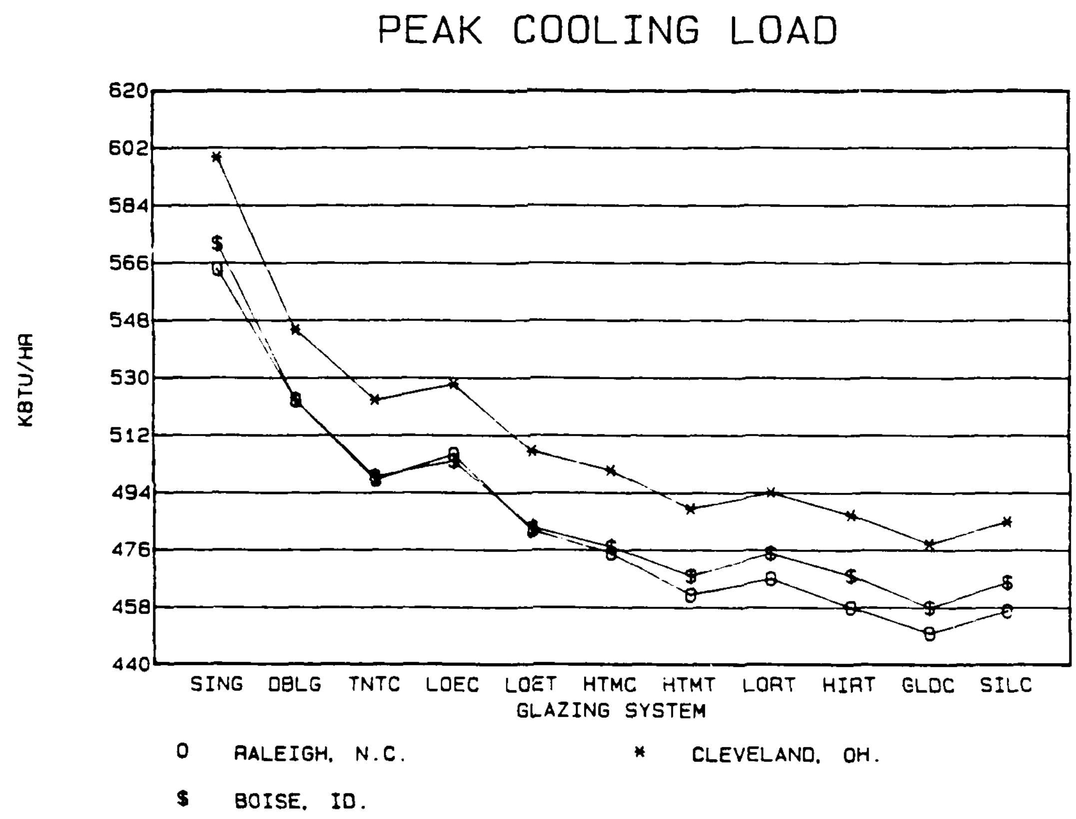

Figure 7: Peak Cooling Load for Raleigh, Boise and Cleveland. Refer to List of Symbols for acronym definitions.

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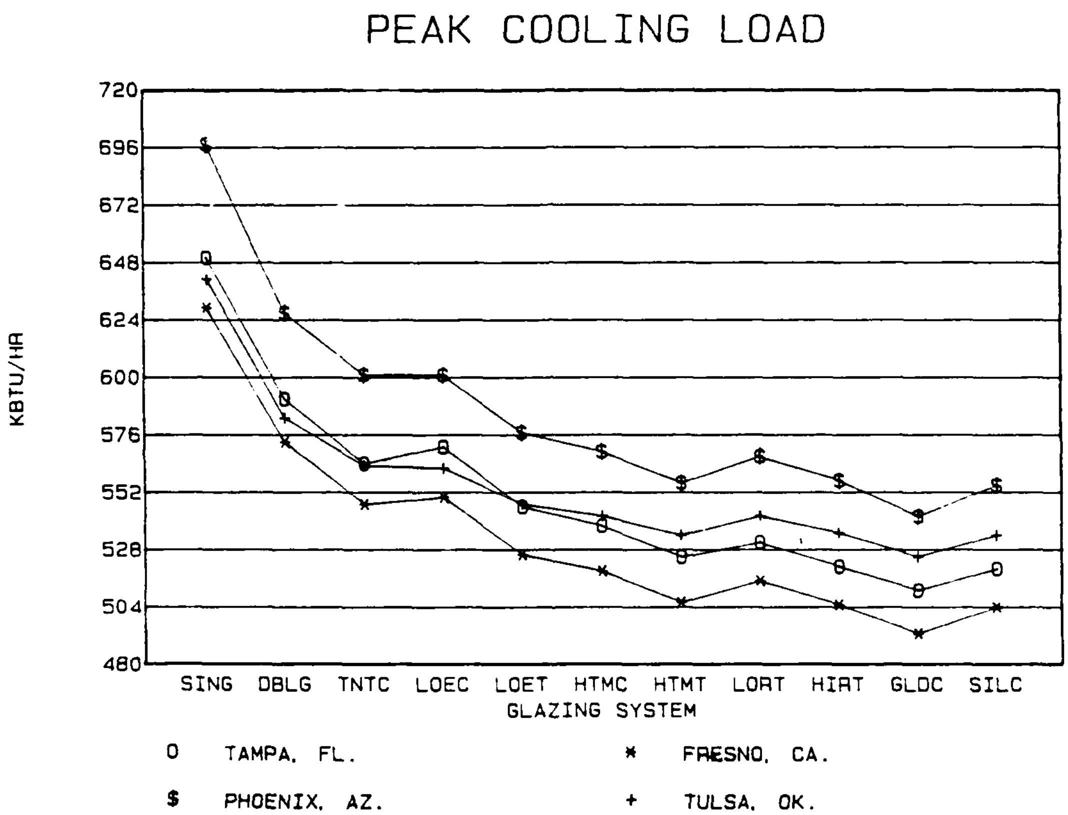

Figure 6: Peak Cooling Load for Tampa, Fresno, Phoenix and Tulsa. Refer to List of Symbols for acronym definitions.

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3.4.2 Peak Cooling Load

The effects of variations in glazing performance on the peak design load were quite similar to the results for annual cooling energy. As shown in Figures 6-8, the low shading coefficient systems within the metallic reflective group showed superior results in effectively reducing the peak cooling loads. The heat mirror system coupled with the tinted external lite, due to its low shading coefficient and low thermal transmittance, performed comparably to the metallic reflective systems in reducing the cooling peaks for most climates.

3.4.3 Annual Heating Energy

The reduction of annual heating energy for cooling load dominated locations is insignificant for those climates in the deep south and southwest. The high level of internal loading in commercial office buildings, as well as the relatively low climatic heating requirements, result in only minor performance effects on heating energy by fluctuating glazing systems. Illustrated in Figures 9-11, as the heating load increases, so does the proportionate importance of the thermal transmittance value.

In the northern climates with larger heating loads the ability of a glazing system to reduce thermal transmittance is essential in reducing the annual heating energy required. In virtually all circumstances the low-emissivity systems,

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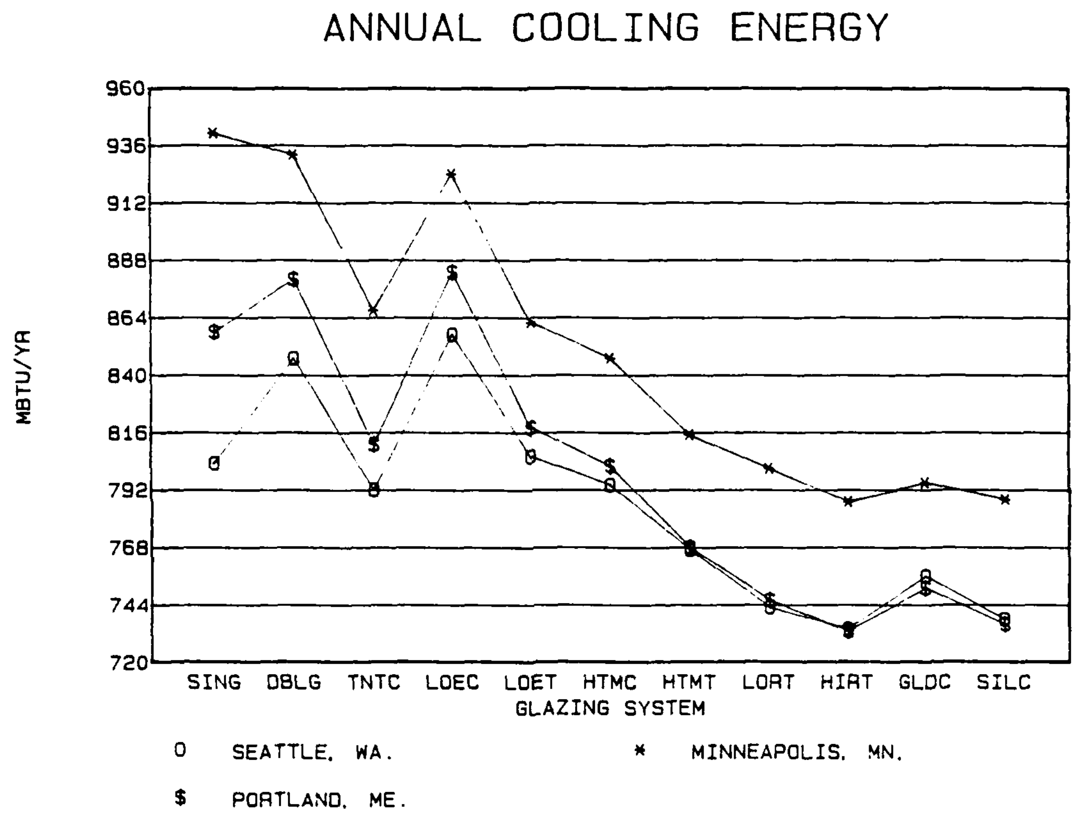

Figure 5: Annual Cooling Energy for Seattle, Portland and Minneapolis. Refer to List of Symbols for acronym definitions.

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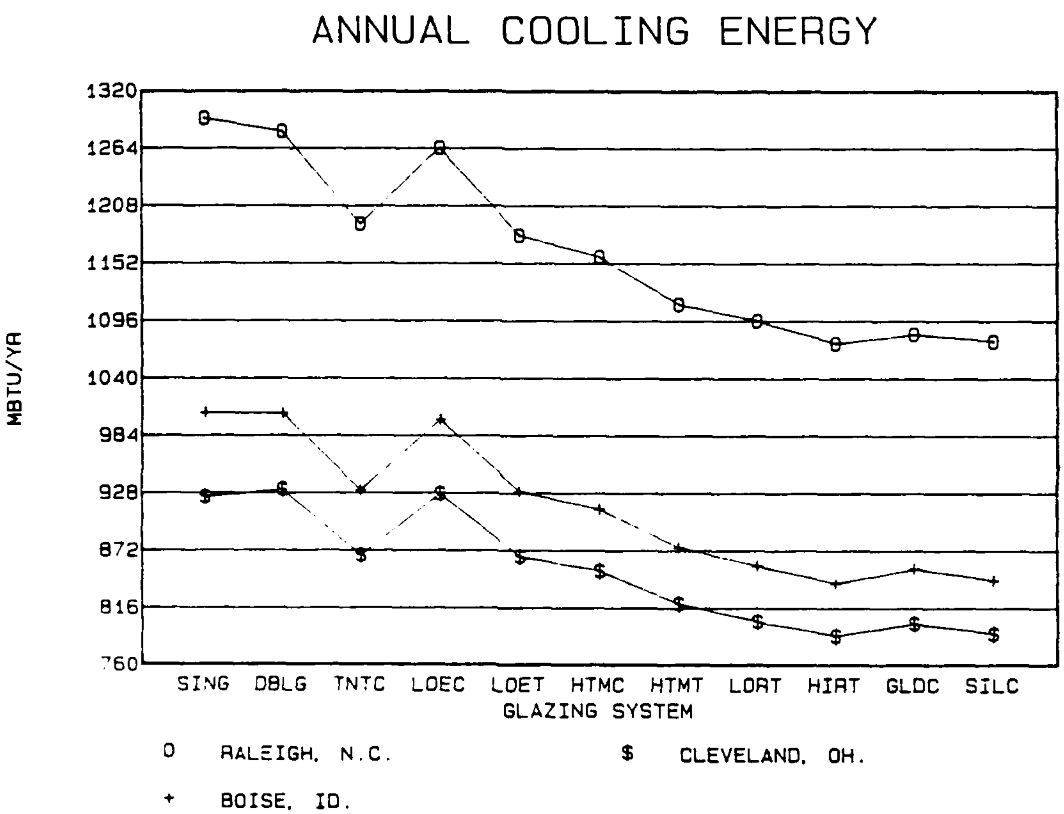

Figure 4: Annual Cooling Energy for Raleigh, Boise and Cleveland. Refer to List of Symbols for acronym definitions.

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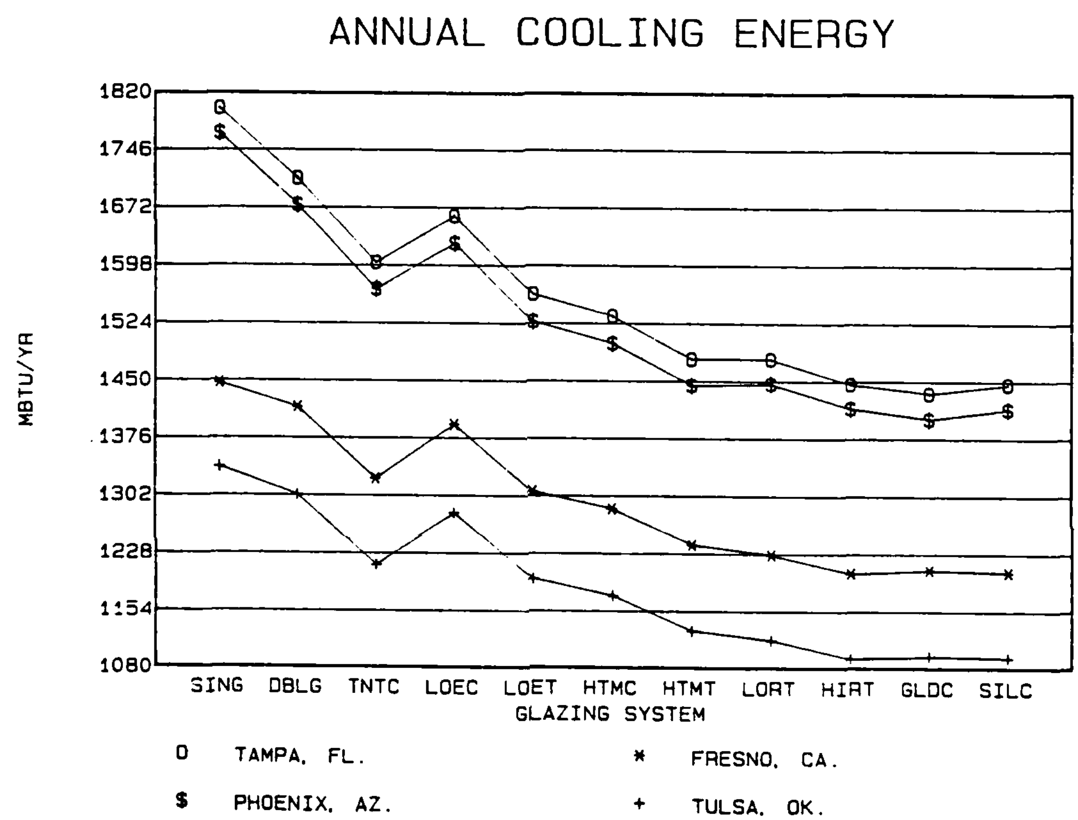

Figure 3: Annual Cooling Energy for Tampa, Fresno, Phoenix and Tulsa. Refer to List of Symbols for acronym definitions.

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3.4 System Energy Performance

Upon modelling the glazing systems into the energy analysis simulation the results were compiled to reflect the effects of variations in glazing parameters on the building energy performance. They were further segregated into the primary energy components of annual cooling, annual heating, peak cooling and peak heating loads. This enabled detailed comparative analysis of the glazing performance effects on the specific energy component considered.

3.4.1 Annual Cooling Energy

Climates having substantial cooling loads are dependent on systems that can reduce solar gain, as illustrated in Figures 3-5. The high reflective metallic coatings demonstrate superior results over the low-emissive or clear glazing systems in reducing annual cooling load.

In evaluating the cooler climates for the effects of glazing type on annual cooling energy, the results appear to be similar to the locations with severe cooling loads. The primary importance of a reduced shading coefficient, toward lowering the cooling energy, is apparent, as well as the insignificance of thermal transmittance on cooling performance variation. Again the metallic reflective systems dominate the reduction of cooling energy over the low-emissive or clear systems.

the far infrared analysis, both low-emissivity coated glass and heat mirror treated film were modelled.

3.3.1 Far Infrared Reflective Systems

Although clear glass can admit around 90 percent of incident near infrared radiation, it is opaque, as all glass is, to far infrared energy. This creates a situation where the longwave heat emitted by the internal warm surfaces can escape the space through absorption in the glass and reradiation in the near infrared range. This process of heat transfer effectively lowers the resistance of the glazing system allowing greater heat transfer between the enviornment and the space. In the summer the incoming gain absorbs into the glass and radiates back into the cooling load. The low-emissivity systems studied have a highly reflective coating that reflects the far infrared radiation back into the space instead of allowing it to absorb in the substrate. This causes the near infrared radiation to be supressed due to the high reflectance of the coating (Rubin,1980). The reduced radiation component increases the resistance of the glazing system greatly. As far as the coated film process, it retains additional surfaces within the airspace to add an aditional improvement by reducing the convective and conductive components as well. Consequently this system further reduces the overall impedance over the glass coated version.

****

Table 5: Performance Parameters of Research Glazing Systems

Acronym (6)	Visible Daylight (1)	Night Wint/U (2)	Day Summ/U (3)	Shading Coeff(SC) (4)	Relative Heat Gain (5)
*******	********	******	******	*********	*********
SINGLS	90	1.16	1.04	1.00	216
DBLGLS	80	.49	.56	.82	171
TNTCLE	67	.49	.57	.55	118
LOECLE	74	.32	.34	.71	145
LOETNT	38	.32	.35	.46	97
HTMCLE	48	.31	.34	.39	82
HTMTNT	22	.31	.35	.25	56
LORTNT	17	.44	.52	.24	55
HIRTNT	7	.41	.49	.16	39
GLDCLE	17	.29	.30	.14	32
SILCLE	7	.41	.46	.16	38
******	**	****	****	****	***

NOTES

(1) The percentage of light in the visible spectrum that is transmitted through the glass.

(2) Winter U-value calculated for outside air temperatures at 0 degrees F, indoor 70 degrees F, outside air velocity at 15mph and solar intensity of 0 Btu/hr/ft2.

(3) Summer U-value calculated for outside air temperature at 90 degrees F, indoor 75 degrees F, outside air velocity at 7.5mph and solar intnsty at 250 Btu/hr/ft2

(4) Ratio between the heat gain of one glazing system versus that of single double strength glass (SINGLS).

(5) Total heat gain through glass in Btu/hr/ft2, calculated for an ASHRAE gain factor of 200 Btu/hr/ft2 with outside air 15 degrees F warmer than indoor air.

(6) Glazing systems studied were 1" units (2- 1/4" lites with 1/2" airspace). SINGLS was single 1/8" glass.

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drastically. The traditional tinted, or heat absorptive, system was also modelled to show lower cost options that still reduced the gain. In the selective transmittance low-emissivity area, systems that selectively reduced the near infrared were tested due to the commercial loading. Within

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Table 4: Composition of Glazing Systems

Acronym	Composition
*******	***********
SINGLS	Single glass annealed clear,ASHRAE reference glass used for base case conditions.
DBLGLS	Double glazing annealed, clear both lites.
TNTCLE	Heat absorptive tinted glass for outside lite, clear annealed inside lite.
LOECLE	Low-emissivity metallic coating on number 3 surface, clear annealed glass both lites.
LOETNT	Low-emissivity metallic coating on number 3 surface, tinted outside and clear inside annealed lite.
HTMCLE	Low-emissivity coating on polyester film, number 3 surface, suspended between two clear annealed lites.
HTMTNT	Low-emissivity coating on polyester film, number 3 surface, suspended between tinted outside and clear inside annealed lites.
LORTNT	Low reflective metallic coating on number 2 surface, on a tinted heat-strengthened lite, inside lite clear annealed.
HIRTNT	High reflective metallic coating on number 2 surface, on a tinted heat-strengthened lite, inside lite clear annealed.
GLDCLE	High reflective gold coating on number 2 surface, both lites clear annealed.
SILCLE	High reflective silver coating on number 2 surface, both lites clear annealed.
******	**

General Note: No coatings were permitted on number 1 or 4 surfaces due to potential deterioration problems.

****

Considering the visible segment, most of the systems vary from one another. As the basis of the research was to consider performance of the glazing systems, conventional interior lighting design was assumed. The performance in the near infrared region ranged from almost full transmissivity in clear, to the high reflective systems that cut the gain

date. Plastics have attained a popular use in their own niche but have failed to replace glass primarily due to their lesser durability, higher cost and poorer optical quality. Glass for architectural applications continues to be modified to react to more stringent energy concerns. The glazing systems that were selected are a representation of current commercial glazing systems available. As shown in Table 4, Table 5 and Figure 2 the criterion chosen depicts a full range of performance parameters and, as will be seen in Chapter 5, economic parameters as well.

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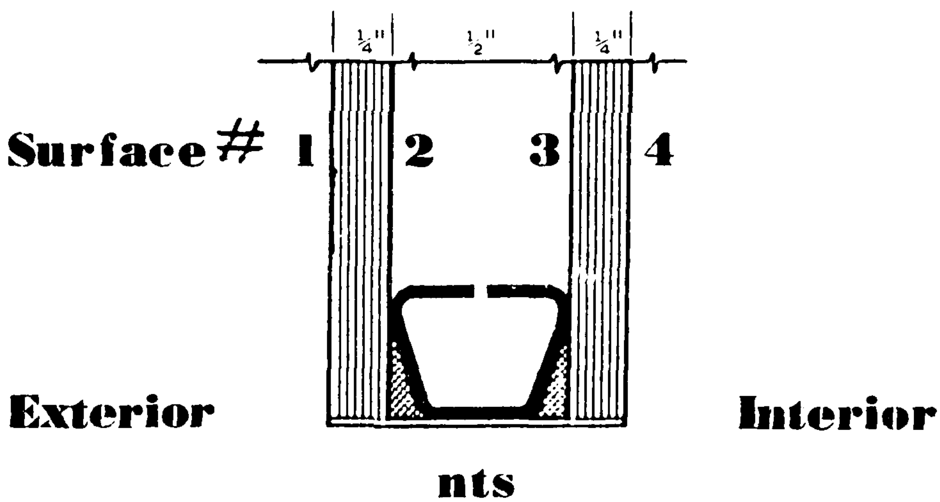

Figure 2: Glazing System Cross Section. Detail showing the numbering of the glazing surfaces and positioning of the lites as applicable to Tables 4 and 5

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Spectrally, the systems all significantly reduce the degenerating ultraviolet waves coming into the space.

T_i = indoor temperature

The thermal transmittance coefficient accounts for the far infrared radiation losses and the conduction/convection losses due to the temperature differentials. The solar heat gain coefficient represents the sum of the solar gain transmitted through the glazing and the inward flow of gain absorbed by the glazing. Following the convention of ASHRAE(1981) the solar heat gain coefficient for double glazing is given by:

$$F = \bar{\tau} + U\alpha_o/h_o + [(U/h_o) + (U/h_s)]\alpha_i \quad (3.5)$$

Where F = solar heat gain coefficient

U = overall heat transfer coefficient

$\bar{\tau}$ = overall solar transmittance

α = solar absorptance of glazing

h_o = combined exterior surface coefficient

h_s = combined air space conductance value

The analysis of the various thermal components was a prerequisite in determining the necessary range of parametrics to study for each catagory of glazing tested.

3.3 Systems Characteristics

Glass fenestration systems remain the mainstay of glazing systems in virtually all architectural applications to this

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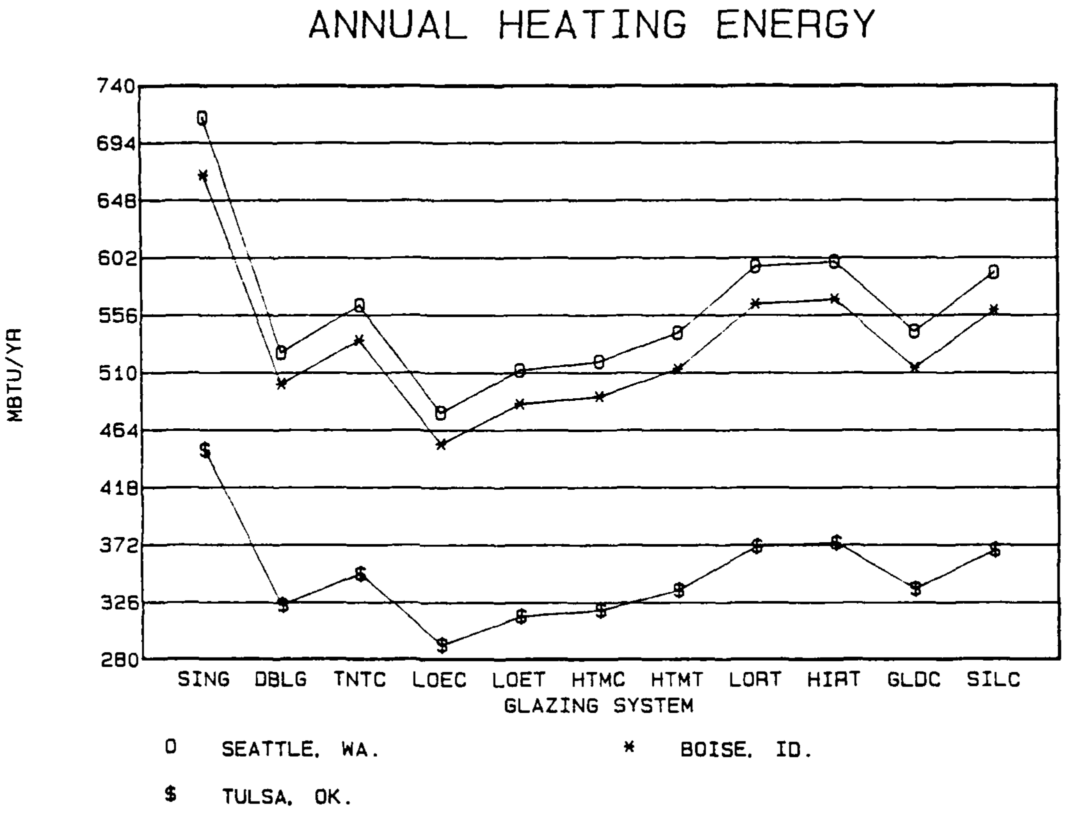

Figure 10: Annual Heating Energy for Seattle, Tulsa and Boise. Refer to List of Symbols for acronym definitions.

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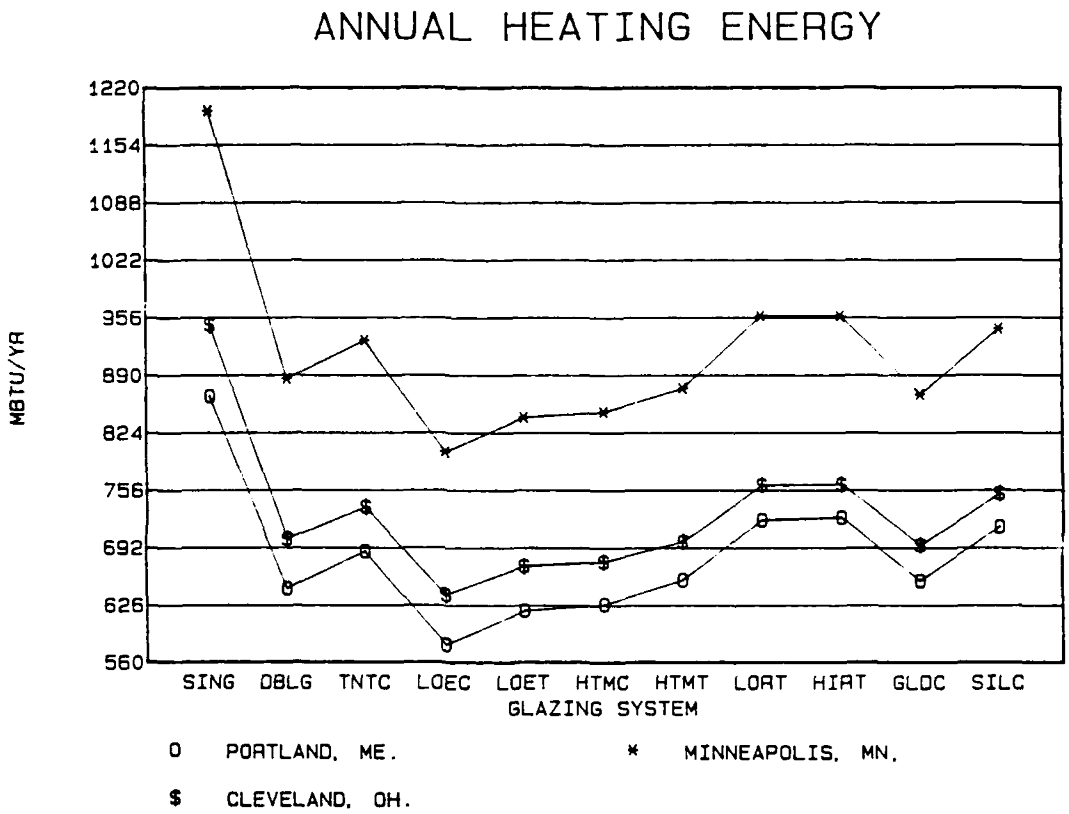

Figure 11: Annual Heating Energy for Portland, Cleveland and Minneapolis. Refer to List of Symbols for acronym definitions.

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through their low impedance values, effectively reduced the heating energy 20-25% over the metallic reflective and clear type systems.

3.4.4 Peak Heating Load

The performance effects on design heating load essentially mirror the results obtained for the annual heating energy. The reduced thermal transmittance, as shown in Figures 12-14, indicates that the low-emissivity systems have the greatest impact on reducing the peak heating load for the climates studied. Conversely, the ability of the high reflective coatings in impacting the heating peaks was even poorer than the clear systems, due to the reflective systems' ability to prohibit useable gain from entering the building and assisting the heating load.

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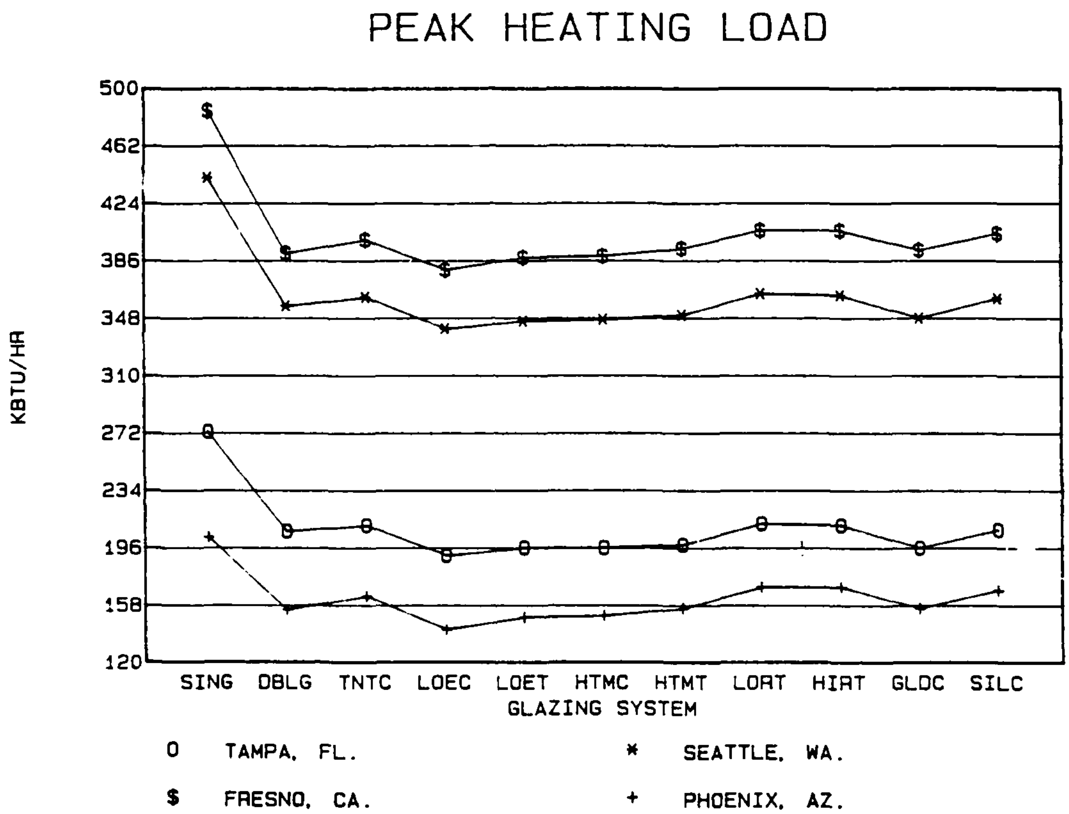

Figure 12: Peak Heating Load for Tampa, Fresno, Phoenix and Seattle. Refer to List of Symbols for acronym definitions.

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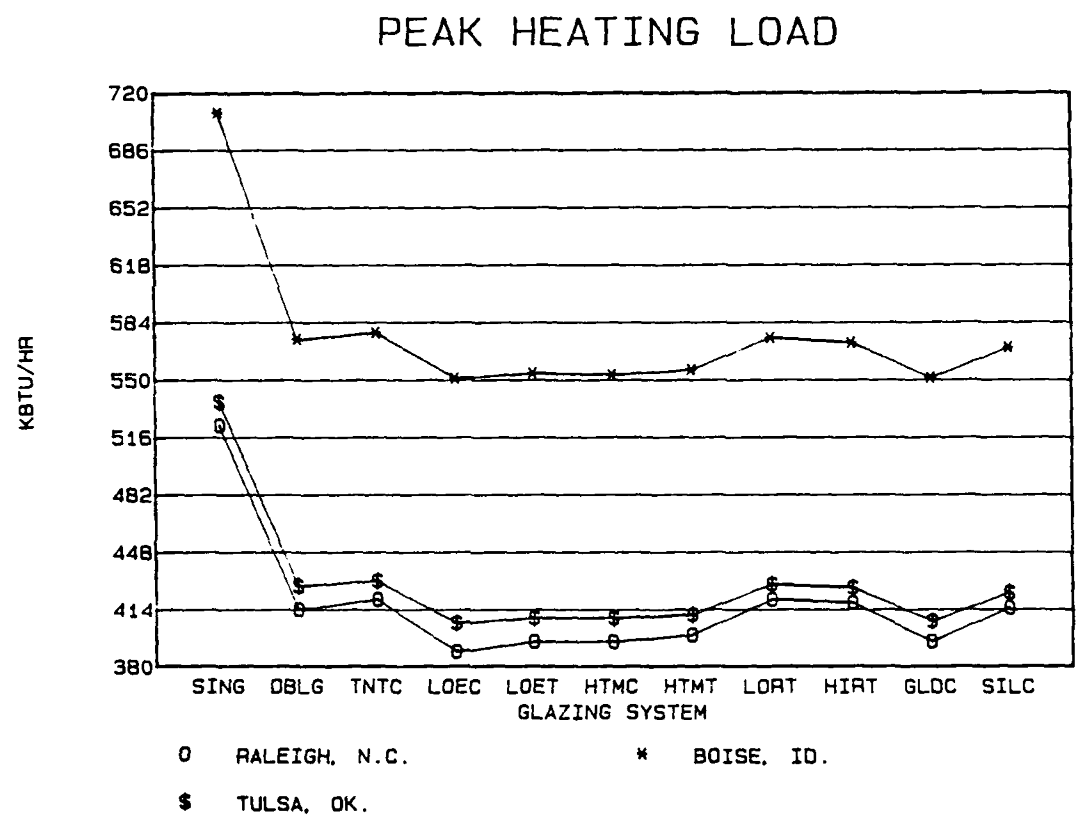

Figure 13: Peak Heating Load for Raleigh, Tulsa and Boise. Refer to List of Symbols for acronym definitions.

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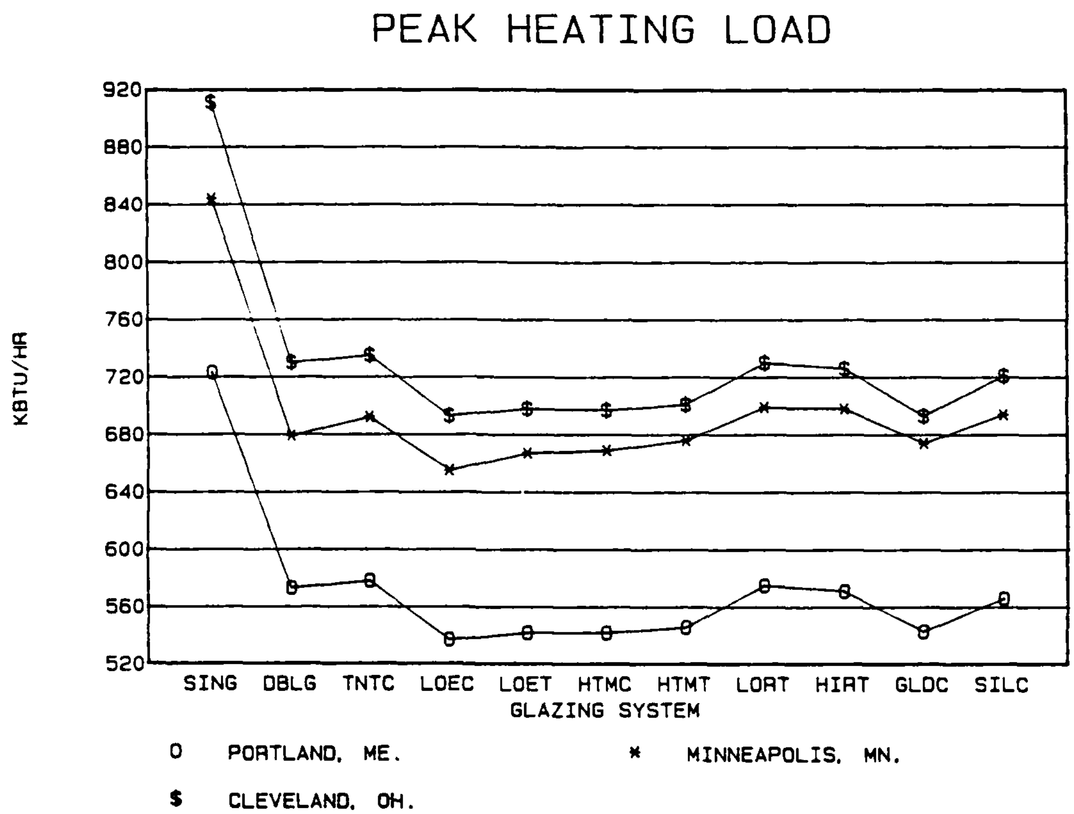

Figure 14: Peak Heating Load for Portland, Cleveland and Minneapolis. Refer to List of Symbols for acronym definitions.

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Chapter 4

MULTIVARIATE REGRESSION ANALYSIS

4.1 Development of Model

Building design professionals currently have a limited selection of tools available to evaluate glazing options for new or retrofit construction applications. Simplistic calculation procedures that account for only gain or impedance give only a generalized assessment of actual loading conditions. The only accurate procedure available involves hour-by-hour mainframe computer simulation, usually at prohibitive costs to the project. The techniques used in this research utilize the power of the DOE 2.1a energy analysis program to reduce the problem of analyzing glazing performance to simple algebraic expressions. These can be used by designers to assess different glazing possibilities for several specific climatic regions. Further refinement and integration of additional climatic variables will formulate expressions useable for a wider range of locations.

The specific analysis accomplished will examine the relationship between a dependent variable and an independent, or group of independent, variables. This process is traditionally classified as either descriptive analysis, where the importance of a specific variable is analyzed, or inferential, where the relationships within the

data sets are evaluated (Nie,et al.,1975). A primary facet of inferential analysis is in evaluating the relationship between a dependent variable and a set of independent variables, as in testing for null hypotheses. Other types of investigation, such as determining the best regression equation and verifying its prediction accuracy, would catagorize under descriptive analysis. The work accomplished for this research encompasses both descriptive and inferential analysis for evaluating several aspects in the correlations. In formulating the predictive model, the independent variables within the population and the effectiveness of the regression equations are assessed. The building energy characteristics will be predicted due to the variation in glazing parameters. This will enable additional evaluation of glazing types to determine the optimum parametric combination for the respective climate.

Inherent in all interrelated investigations is the difficulty of isolating the specific nature of the problem. An initial objective was determined in the statistical analysis on which all further evaluations were based. The purpose of this investigation is to predict building energy conditions as a function of fluctuating glazing impedance and shading coefficient parameters. Climatic variables, in an additional segment of analysis, will be integrated within the correlations to provide predictor equations that accurately determine building energy conditions as functions of both glazing and climatic parameters.

The parameters used for the initial analysis were carried over from the parametric variations of the initial DOE 2.1a runs. In analyzing glazing performance qualities, overall conductance and shading coefficient govern the results. Consequently these were the independent variables selected for the initial regressions. The dependent variables used were the yearly cooling and heating loads, as well as their peak conditions. As the objective was to study glazing performance alone, all other input values related to the building were held as constants. The second group of independent variables evaluated was in conjunction with determining climate generalized correlations. The variables analyzed were all commonly available terms based on yearly weather data. After numerous trial-and-error runs, a select group of potentially predictive values was chosen. Table 6 lists the dependent and independent variables used for this analysis with their respective units.

After analyzing the objectives of the study and determining the variables which will be used, evaluation of the procedures that will be used is necessary. The multiple regression methodology permits study of the linear relationship between a set of independent variables and a dependent variable while taking into account the interrelationships among the independent variables (Sullivan and Nozaki,1984). Formulation of predictor equations from the effects of known independent variables, or unknown

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Table 6: Variables Selected For Regression Analysis

Variable	Definition	Units
********	**********	*****
CLLD	Total Cooling Energy	$MBtu/Yr/Ft^2$
CLPK	Maximum Cooling Load	$KBtu/Hr/Ft^2$
HTLD	Total Heating Energy	$MBtu/Yr/Ft^2$
HTPK	Maximum Heating Load	$KBtu/Hr/Ft^2$
UVALSUM	Overall Conductance	$Btu/Hr/Ft^2$
SHADCOEF	Shading Coefficient	unitless
LAT/DEG	Latitude	Degree
WINTEMP	Winter 97.5% Des Temp	^{O}F
SUMTEMP	Summer 2.5% Des Temp	^{O}F
HDD/B65	Heatng Deg Days(Base 65)	$(^{O}F)(Day)$
CDD/B65	Coolng Deg Days(Base 65)	$(^{O}F)(Day)$
MDSR/Jan	Mean Daily Solar Rad(Jan)	Langleys
MDSR/Jul	Mean Daily Solar Rad(Jul)	Langleys
********	************************	********

Note:

CLLD,CLPK,HTLD & HTPK are dependent variables, the remainder being independent variables.

****

dependent variables, is a typical regression approach using the descriptive procedures covered earlier in this chapter. Relating the variables in equation form illustrates the following as the general form of the regression:

$$Y' = A + B_1X_1 + B_2X_2 + \ldots\ B_kX_k + e \tag{4.1}$$

where

Y' = the estimate value for Y (Y-Hat)

A = the Y intercept

B's = regression coefficients

X's = independent variables

e = random error off regression fit

The number of independent variables designates this procedure as multiple, rather than simple linear, regression. An exponential increase in an independent variable will alter the order of the equation, from a first order equation, to the exponential degree of order that the variable is assigned (Draper and Smith,1966). The predictor equations derived for this research used varied order solutions depending on the development of the equations. Another form of variable refinement that can serve to increase precision in a correlation is the transformation. The use of statistical transformations, such as -1/X or log(X), evaluates a specific function of an independent variable to reduce abnormalities in residual patterns. The several transformations used in this research allowed for a superior fit of the coefficients. The actual intercept and regression coefficients are derived by calculating when the sum of squared residuals $SUM(Y - Y')^2$ is minimal. This is termed the least squares approach and it implies that other A or B values would result in a larger sum of squared residuals, a poorer fit equation (Nie,et al.,1975). Determining the optimum intercept and coefficient values suggests a maximum correlation between the calculated and predicted dependent variables, while the correlation between the independent variables and the error is lessened. The procedures involved in multiple regression lend themselves

to computer simulation due to the vast quantity of complex numerical calculations required. MINITAB version 82.1 is a powerful statistical analysis program developed by The Pennsylvania State University Department of Statistics for use on the university's IBM 3081 mainframe computer. This statistical package was used in this research for thoroughly developing both the predictor equations and the correlations. The descriptive statistics in the program made MINITAB well suited for comparing the results with the set objectives.

4.1.1 Statistical Objectives

Upon defining the procedure that would be used in the analysis, performance objectives were set to assure the accuracy of the objective results. Standard regression methodology (Draper and Smith,1966) directs that in order for a predictor equation to be considered accurate, several specific target areas need to be evaluated for acceptability.

The R^2 term is the ratio of explained variation in the dependent variable, Y, to the total variation in Y. Statistically called the coefficient of determination, it is the segment in the variation within Y that can, in fact, be explained by the predictor equation derived. Assessed in a percentage between 0%(.00) and 100%(1.0), a 0% designation would indicate a total lack of correlation between the

equation and the dependent variable. Similarly, a value of 100% indicates a perfect predictor of Y. The R^2 target was set at 90% to maintain a high degree of prediction accuracy for the correlations.

The variables selected do not necessarily have a direct correlation to the predictor equation derived. A certain probability exists that out of the quantity of parameters selected for analysis, certain values will be statistically insignificant in solving for the dependent parameter. MINITAB performs a detailed analysis, called the T-ratio, which evaluates the significance of the input variable relative to the remainder of the independent variables evaluated. Upon examination of the variables it was determined that the target range for the significance would be set at values greater than 2.0. Values less than this would be generally be considered insignificant enough to warrant exclusion from the study.

A traditional assessment of variation within the regression analysis is the standard deviation of actual Y about the predictor Y. This evaluation procedure verifies model precision in estimating the error of the predicted equation, to the actual value quantity. A proportionate high deviation suggests that the model is yielding an innacurate predictor equation. A lower figure points toward a higher compatability with the predictor equation and a more precise result (Nie,et al.,1975). The target range for the standard

deviation was set at 1.0. Errors that fell at or below this range were considered at an acceptable level of deviation from the actual quantity calculated.

In closing the analysis of a set of regression correlations the ability for the equations to continue their precision, until the objectives have been met, requires that the equation be evaluated for its long term sustainability. According to Nie,et al.(1975), this is accomplished by examination of the correlations' residual plots. This is the difference between Y and Y' variables plotted against the independent variables. Analysis of the plots will either reveal a plot with good distribution, or one that requires further refinement. A well-proportioned plot has its values randomly scattered showing no indication of a deliberate pattern. Conversely, a plot requiring transformations or other statistical alterations would exhibit hyperbolic or increasirg proportions. The residual plots for this research are shown in Appendix C for both the individual region components and the generalized climatic correlations. The plots were examined for deviations to acceptable plot requirements. Those equations with integrated transformations developed results, at an early stage of analysis, that warranted refinement of the variables to rectify the residual plots.

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Table 12: Commercial Pricing of Glazing Systems

System	Cost	*	System	Cost
******	****	*	******	****
DBLGLS	$3.15		TNTCLE	$3.55
LOECLE	$4.47		LOETNT	$4.90
HTMCLE	$6.00		HTMTNT	$7.09
LORTNT	$8.50		HIRTNT	$8.50
GLDCLE	$9.50		SILCLE	$7.40
******	*****	*	******	*****

where

Costs are in $/ft^2$

DBLGLS = Two clear glass lites

TNTCLE = Tinted outside lite-clear inside lite

LOECLE = Clear outside lite-low emissivity inside lite

LOETNT = Tinted outside lite-low emissivity inside lite

HTMCLE = Low emissivity film between two clear lites

HTMTNT = Low emissivity film between tinted-clear lites

LORTNT = Low reflective tinted out-clear inside lite

HIRTNT = High reflective tinted out-clear inside lite

GLDCLE = High reflective gold outside-both clear lites

SILCLE = High reflective silver out-both clear lites

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distillate fuel, natural gas, steam coal and electricity. Cooling systems were modelled as either traditional electric or steam-driven absorbtion chillers. The following plant efficiency factors were used in evaluating the energy quantities: electricity(1.0), distillate fuel(.6), natural gas(.7) and steam(.3). The electrical cooling coefficient of performance (COP) was set at 2.0 while absorbtion chiller systems were evaluated at a .6 efficiency. Specific and accurate energy prices, as in investment costs, were essential in modelling a thorough life-cycle cost analysis.

standardized with costs reflecting a set quantity of specific sized insulated glass units, manufacturer's volume pricing, and total costs based on a standard freight structure. The ten glazing systems and their respective prices are illustrated in Table 12. A decision was made, early in the study, to include only material prices in the initial cost input. Labor, overhead and profit were not included, primarily to assist in the new construction analysis. For new construction evaluations, isolating the glazing system from costs indirectly involved added to the evaluation credibility. In the case of retrofit study the addition of an equal, fixed installation cost would only serve to extend the payback period out in time. As the purpose of this study was to evaluate life-cycle costs, for both retrofit and new construction, the analysis of payback time was not determined a requirement. Another primary parameter to this analysis is that of energy assessment.

Much of the economic analyses being carried out for energy-related, large-scale evaluations are accomplished using dated, average national energy costs. Appendix C details the energy pricing data (U.S. Department of Energy,1984) that was used in this study. It represents the latest regional energy costs and their respective escalation rates over the 25-year test period. The glazing systems were tested for ecomomic performance under several building energy systems. Represented heating system fuels included

5.2 Economic Simulation

The economic analysis of a life-cycle cost study incorporates numbers of integrated calculations, making it ideal for computational accomplishment. This study evaluated the cost effectiveness of eleven glazing systems for ten climatic regions. Each glazing system was subsequently evaluated for five separate energy systems to establish correlations between regional energy costs and variations in the building component loads. Total present value costs were combined for each system so that they could be compared within their respective regions.

Using the guidelines of the Life-Cycle Costing Manual for the Federal Energy Management Programs (Ruegg,1980), the analysis was accomplished. An integrated life-cycle costing program, developed by the National Bureau of Standards, was used for over 550 runs in completing this analysis. Along with the seven percent discount factor, the total project life was required. A life expectancy of 25 years was used to illustrate a project span realistic for new construction and for retrofit of a permanent facility in adequate condition. The primary factors in a life-cycle cost evaluation are usually the initial investment and energy related costs.

A common base for parameters is necessary in evaluating initial costs for comparative systems. The initial investment costs, for this research, were determined by commercially aquired pricing data. Prices were equally

procedure considers significant costs, over time, of a building's design, components, materials and operation. It includes factors such as the initial investment cost, future replacement cost, operation and maintenance cost, and salvage values.

A life-cycle cost economic model converts the cost amounts, associated with a given project, to a common time for making all quantities the same comparable value. That quantity is further adjusted for inflation, which is a quantity that represents a decline in general purchasing power. The opportunity cost for money, which is the expected rate of return on money as an investment instrument, also adjusts the life-cycle cost model. The inflation parameter was held as a constant through the test based on the assumption that future prices were expected to change at the same rate as general inflation, therefore, rendering the project costs unchanged in terms of present costs. The opportunity costs were adjusted to correspond with potential investment availabilities. Through a seven percent real discount rate, the opportunity cost of money less inflation, the present costs compensated for the actual cost of money expended over the project life.

Chapter 5

LIFE-CYCLE COST EVALUATION

5.1 Development of Model

The overall performance of a glazing system takes into consideration more than just its ability to fluctuate the heating and cooling components of a building's energy requirements. While a specific system might equate to being successful in reducing energy, theoretically, the effects it has on all required energy sources including initial investment cost need to be examined over the full economic life. This strategy can also be used to assess the cost effectiveness of several systems together in selecting an alternative with superior economic characteristics. Prior to examining the data, an organized model must first be planned and specific objectives defined.

The primary objective for this study was to determine the comparative degree of cost effectiveness for the tested glazing systems in each of the ten climatic regions. As well, economic results were derived for use by designers in both new construction and retrofit markets. With these caveats in mind, the mode of analysis consisted of a method dealing with total long-term project costs and shorter-term payback analysis. Recent economic evaluations (Treado,et al.,1983b) suggest effective results using life-cycle costing methods supported with current energy costs. This

falls within target limits: however, the R^2 term falls short of requirements. Various combinations of orders and variables were evaluated resulting in this equation having the best fit. This appears to demonstrate the lack of total accuracy inherent with analyzing a limited climatic population of only 10 regions. Examining the standard deviation and T-ratio tests reveals values well within the target set.

The heating load evaluation derived an equation in the second order. The coefficient of determination term and T-ratio significance displayed no problems. The standard deviation value, however, fell fractionally outside the target range. This degree of deviation is not considered to be critical and was judged to be at the extreme end of acceptable limits.

Similar conclusions for the heating peak were determined from these results. A first order equation with two transformations was used. The coefficient of determination and T-ratio significance each fell within the acceptable ranges. Again, a slight increase in the standard deviation statistic was noticed, but judged acceptable in view of population size and level of magnitude outside the acceptable target range.

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Table 11: Climate Generalized Regression Equations and Coefficients

$$\text{Cooling Load} = A + B_1\text{UVALSUM} + B_2(\text{SHADCOEF})^2 + B_3\text{LAT/DEG} + B_4\text{CDD/B65} + B_5\text{MDSR/JUL} + B_6(\text{LAT/DEG})^3 \quad (4.6)$$

where $A = 45.3$ $B_1 = -1.83$ $B_2 = 6.16$
$B_3 = -1.21$ $B_4 = .0019$ $B_5 = .0181$
$B_6 = 1.5(10^{-4})$

and $R^2 = .979$ Std.Dev. $= .844$

****

$$\text{Cooling Peak} = A + B_1\text{UVALSUM} + B_2(\text{SHADCOEF})^2 + B_3\text{SUMTEMP} + B_4(\text{CDD/B65})^2 \quad (4.7)$$

where $A = 4.87$ $B_1 = .756$ $B_2 = 1.81$
$B_3 = .0464$ $B_4 = 8.91(10^{-8})$

and $R^2 = .864$ Std.Dev. $= .320$

****

$$\text{Heating Load} = A + B_1\text{UVALSUM} + B_2\text{SHADCOEF} + B_3(\text{HDD/B65})^2 + B_4\text{MDSR/JAN} + B_5(\text{MDSR/JAN})^2 \quad (4.8)$$

where $A = 6.41$ $B_1 = 4.89$ $B_2 = -2.11$
$B_3 = 1.92(a)$ $B_4 = -.0253$ $B_5 = 1.4(10^{-5})$
(a) 10^{-7}

and $R^2 = .961$ Std.Dev. $= 1.11$

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$$\text{Heating Peak} = A + B_1\text{UVALSUM} + B_2\text{SHADCOEF} + B_3\text{WINTEMP} + B_4\text{MDSR/JAN} + B_5(1/\text{WINTEMP}) + B_6(\text{Sqrt MDSR/JAN}) \quad (4.9)$$

where $A = 2.26$ $B_1 = 2.22$ $B_2 = -.405$
$B_3 = -.160$ $B_4 = -.076$ $B_5 = 1.86$
$B_6 = 1.71$

and $R^2 = .905$ Std.Dev. $= 1.12$

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Table 10: Heating Peak Regression Equation and Coefficients

$$\text{Heating Peak} = A + B_1\text{UVALSUM} + B_2\text{SHADCOEF} + B_3[(\text{Sqrt})\text{UVALSUM}] + B_4(-1/\text{SHADCOEF}) \quad (4.5)$$

City	Regression Coefficients A	B_1	B_2	B_3	B_4
Tampa	3.46	1.45	-2.74	.101	$9.2(10^{-4})$
Seattle	6.35	1.18	-.368	.548	$4.4(10^{-5})$
Raleigh	6.88	1.71	-.399	1.01	$1.1(10^{-4})$
Portland	11.7	7.81	-.267	-5.88	-.012
Minneapolis	12.6	1.98	-.853	.809	$6.5(10^{-5})$
Fresno	7.40	1.04	-.579	.424	$5.0(10^{-5})$
Cleveland	12.5	2.63	-.240	1.10	$1.6(10^{-4})$
Boise	10.2	1.72	-.182	.674	$9.5(10^{-5})$
Phoenix	2.40	.741	-.602	1.05	$5.9(10^{-5})$
Tulsa	7.30	1.54	-.168	.715	$1.0(10^{-4})$

Statistical Tests

City	R^2	Std.Dev.	City	R^2	Std.Dev.
Tampa	.99	.00052	Seattle	.99	.00021
Raleigh	.99	.00028	Portland	.99	.00626
Minneapolis	.99	.00032	Fresno	.99	.0001
Cleveland	.99	.00017	Boise	.99	.0001
Phoenix	.99	.00038	Tulsa	.99	.0001

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Table 10 illustrates the last of the individual climate components: the correlations for the heating peak analysis. The standard deviation error and coefficient of determination results suggest an accurate fit correlation. Use of a first order equation with two transformation components was necessary for an acceptable residual fit.

4.2.2 Climate Generalized Analysis

All of the climate generalized correlations are illustrated in Table 11. These predictive equations were each derived from over one thousand data points using the same methodology as the individual climate analysis. The population, however, was still considered minimal to complete a detailed climate analysis (Johnson,et al.,1983). Related studies have indicated researchers simulating over 2500 simulation runs, costing in the tens of thousands of dollars, to build a large enough data base. Regardless of these constraints the task was undertaken and considerable success was obtained.

The cooling load prediction fits extremely well within the target ranges of R^2 and standard error. As well, all variables show solid significance proportions in the T-ratio test. The equation derived is a third order prediction with good residual distribution.

A second order equation was formulated for analyzing the parametric effects on cooling peak. The standard deviation

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Table 9: Heating Load Regression Equation and Coefficients

Heating Energy = A + B_1UVALSUM + B_2SHADCOEF (4.4)

City	Regression Coefficients A	B_1	B_2
Tampa	.8960	.728	-.530
Seattle	9.470	5.95	-2.80
Raleigh	5.030	3.72	-1.88
Portland	11.72	7.73	-3.28
Minneapolis	15.00	9.43	-3.10
Fresno	2.710	2.72	-1.44
Cleveland	12.10	7.38	-2.66
Boise	8.890	5.85	-2.65
Phoenix	1.140	1.45	-8.46
Tulsa	5.810	3.97	-1.92

Statistical Tests

City	R^2	Std.Dev.	City	R^2	Std.Dev.
Tampa	.98	.0155	Seattle	.99	.0404
Raleigh	.99	.0294	Portland	.99	.0538
Minneapolis	.99	.0401	Fresno	.99	.0306
Cleveland	.99	.0378	Boise	.99	.0436
Phoenix	.98	.0293	Tulsa	.99	.0279

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Table 8: Cooling Peak Regression Equation and Coefficients

$$\text{Cooling Peak} = A + B_1\text{SHADCOEF} + B_2(\text{UVALSUM})^2 + B_3(\text{SHADCOEF})^2 + B_4(-1/\text{UVALSUM}) \quad (4.3)$$

City	Regression Coefficients A	B_1	B_2	B_3	B_4
Tampa	10.1	.591	.969	.591	.026
Seattle	8.82	1.44	.654	.014	.054
Raleigh	8.82	1.88	.468	.018	.035
Portland	8.46	1.72	.528	.014	.042
Minneapolis	9.35	1.47	.599	.012	.048
Fresno	9.75	1.89	.841	.024	.070
Cleveland	9.41	1.69	.567	.013	.043
Boise	9.32	.873	.443	.676	.083
Phoenix	10.8	1.92	1.02	.042	.088
Tulsa	10.5	.591	.969	.591	.026

Statistical Tests

City	R^2	Std.Dev.	City	R^2	Std.Dev.
Tampa	.99	.00046	Seattle	.99	.00044
Raleigh	.99	.00051	Portland	.99	.00039
Minneapolis	.99	.00039	Fresno	.99	.00068
Cleveland	.99	.00038	Boise	.99	.0066
Phoenix	.99	.0010	Tulsa	.99	.0121

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Table 7: Cooling Load Regression Equation and Coefficients

$$\text{Cooling Energy} = A + B_1\text{UVALSUM} + B_2\text{SHADCOEF} + B_3(\text{UVALSUM})^2 + B_4(\text{SHADCOEF})^2 \quad (4.2)$$

City	Regression Coefficients A	B_1	B_2	B_3	B_4
Tampa	27.4	.952	7.66	-.621	.282
Seattle	15.3	-1.60	3.17	-1.36	.613
Raleigh	21.1	-.819	6.05	-1.02	.440
Portland	14.8	-.730	4.09	-2.14	.751
Minneapolis	15.5	-.170	4.11	-1.50	.537
Fresno	23.5	-.342	6.14	-1.07	.482
Cleveland	15.7	-.510	4.05	-1.55	.511
Boise	16.8	-.820	4.60	-1.44	.684
Phoenix	26.6	1.860	7.38	-1.51	.481
Tulsa	21.2	-.265	6.08	-.945	.435

Statistical Tests

City	R^2	Std.Dev.	City	R^2	Std.Dev.
Tampa	.99	.0054	Seattle	.99	.0190
Raleigh	.99	.0135	Portland	.99	.0263
Minneapolis	.99	.0188	Fresno	.99	.0137
Cleveland	.99	.0190	Boise	.99	.0194
Phoenix	.99	.0131	Tulsa	.99	.0123

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along with applicable statistical test results. A second order equation was derived and reduced to a per square foot form. The coefficients of determination values, as well as the standard deviation, were well within target limits. T-ratio testing revealed sporadic statistical insignificance for the glazing coefficient of heat transmission. The shading coefficient establishes the primary parameter for cooling load analysis. The conductance parameter was retained in the equation due to the occasional significance and the need for increased accuracy in evaluating both parameters.

The statistical correlations for cooling pea are presented in Table 8. The equation derived is second order using two transformations for achieving proper residual distribution. The coefficient of determination and standard deviation again displayed a highly accurate prediction. The t-ratio emphasized the shading coefficient; however, all other independent variables displayed acceptable significance.

A much simpler model was generated for evaluating the heating load component. As shown in Table 9, a first order equation was developed and accurately predicts variations in heating loads due to glazing parameter changes. The statistical tests showed a high degree of precision with no apparent problems. The variables also indicated a strong significance for their respective climates.

4.2 Statistical Results

The technique used in this research consists of the creation of a large data base from a series of DOE 2.1a energy analysis simulations. As described in Chapter 2, a representative low-rise commercial building was analyzed for the effects of glazing performance on energy requirements. This was accomplished for eleven glazing systems in ten climatic regions, as illustrated in Chapter 3. Initial regression analysis evaluated the effects of glazing parameters on climatic locations, solving for each specific region. Follow-up research examined the integration of numerous significant variables in a larger data base to determine a set of climate generalized correlations for broader climatic use. Both individual location and climate generalized results were included as a result of the extremely accurate results for the individual regions. The individual location correlations are considered superior to the less accurate generalized results, for those specific regions. The climate generalized correlations would be used over the individual climate equations if the climatic values differed significantly from the individual cities examined in this study.

4.2.1 Individual Climate Analysis

The regression equation and resulting coefficients for the cooling load correlations are presented in Table 7,

5.3 Economic Results

The study uses several modes of analysis in evaluating economic results. Each method examines different aspects applicable to either new or retrofit situations. The methodology used consists of total life-cycle costs, savings-to-investment ratios, and present value energy costs. All of the methods evaluate energy in monetary terms, for specific geographical regions, and equate costs for present value after being adjusted for future escalation.

Total life-cycle cost analysis is the total of all relevant economic costs in a project, in present value terms. It incorporates the sum of all investment, operation, maintenance, replacement and energy costs, while subtracting out a salvage value for the project. It is ideally suited for comparative analysis in new building designs and for evaluating equivalent alternatives in retrofit applications (Ruegg,1980). For this study the total life-cycle costs were established for each glazing system in all ten climatic regions. The resulting quantities represent total life-cycle investment and energy costs over the simulation period. Specific values should not be used as an anticipated cost, but as a proportionate degree of savings over systems with higher total costs.

A savings-to-investment ratio analysis traditionally evaluates potential retrofit alternatives that are distinctively different in costing structure. This procedure

enables a designer to rank order dissimilar projects based on the significance in savings over time. Specifically, the analysis is a calculated numerical ratio between the reduction in energy costs and the increase in investment costs. A ratio of 1.0 or higher is considered cost effective with the higher ratio describing an investment with a greater amount saved per amount expended. For this study, considering the equivalence in project costing structure, the savings-to-investment ratio is shown to compare the potential investment restitution over time. The evaluation compared the tested systems to a base, clear monolithic glazing system. These results can be useful for projects with strong concerns about short term paybacks, such as retrofit applications for buildings with a limited anticipated life span.

Understanding and examining the present value energy costs give insight into actual energy performances of glazing systems over a longer period of time. This mode of analysis evaluates only the project energy cost, appropriately escalated, for the entire study period. Using this procedure, the performance of the systems can be studied with respect to changes in energy systems and geographic region. Although not typically used for comparative evaluation, projects being designed with concern over future operation costs, but enjoying a flexible initial budget, would find these results apropos.

5.3.1 Present Value Energy Costs

Considering only the energy associated costs for the glazing systems, the results were compiled for their respective climatic region and displayed in Appendix C. Standing out in overall performance, for several locations, was the gold-coated reflective glazing. This system exhibits the thermal impedance qualities of low-emissivity glazings and the traditional reduced radiant gain of reflective glass. It reduces heating and cooling energy costs above the level of comparable systems for cooling load dominated climates located in the deep south or southwest. Similar results were achieved with the other reflective systems; however, non-reflective systems fared significantly poorer in southern climates.

For locations with substantial heating load and moderate cooling requirements, such as Minneapolis, the gold reflective and the low-emissivity systems were equally superior in performance. This indicates a performance trade-off between useable gain to offset heating load and unwanted gain in the summer cooling season, while thermal transmittance remained almost equal. Climatic areas with reduced cooling loads and significant heating requirements were successful using the low-emissivity systems solely. Intermediate locations with energy requirements for both heating and cooling generally favored the gold reflective system. In general, depending on degree of cooling

requirement and energy source used, the low-emissivity systems displayed comparable performance to the gold reflective system in most climates except the extreme south. In no situation, however, did the clear, tinted or traditional reflective systems show a performance advantage in energy costs.

5.3.2 Savings-to-Investment Ratio

This analysis compares the savings experienced, over a single glazed base system, in a ratio of saved energy costs to expended investment costs. The values represent, as shown in Appendix C, a system experiencing cost effectiveness in the shortest span of time. This does not, therefore, account for more efficient systems returning more on investment at later stages of the evaluation period. The results generally favored the lowest cost systems that provided a cost effective solution to single glass. In the cooling load dominated climates, tinted heat-absorbing glazing produced the highest ratio. Closely behind, the low-emissivity system with the heat-absorbing exterior lite fared comparably. For the heating load climates, the traditional clear insulated glass edged out the clear low-emissivity systems as the system with the most advantageous short range economic potential. The moderate climates resulted in a distributed mix of clear and tinted systems again, just slightly ahead of the low-emissivity systems. It is

interesting to point out that although the lower cost tinted and clear systems had leading savings-to-investment ratios, the low-emissivity systems trailed only slightly behind regardless of the substantially higher initial costs.

5.3.3 Total Life-Cycle Costs

The evaluation of total life-cycle costs is perhaps the most significant economic quantity building designers can use for both retrofit and new construction analysis. For permanent facilities, these results, based on the total cost evaluation over a building's life, should be employed for comparative studies. The results, as shown in Figures 15-24, without question suggest that low-emissivity systems dominate total life-cycle performance for heating load situated climates. Depending on the severity of the radiant gain, some locations favored the heat-absorbing lite with the low-emissivity interior lite. Although the lower cost coated glass low-emissivity systems fared better overall, the suspended film version remained close behind. These results indicated that with a lower initial cost the suspended film low-emissivity systems would dominate many catagories of total life-cycle analysis.

Regions requiring substantial cooling requirements showed mixed results. Climatic regions such as Raleigh favored the tinted low-emissivity solutions. However, as the cooling load increased the advantages of low-emissivity decreased.

Locations exhibiting negligible heating requirements and severe cooling loading were aided by the ability of reflective systems to act on the solar gain over other systems. Intermediate areas with significant cooling and heating loads pointed towards the low-emissivity solution as long as there was a respectable heating requirement. The higher cooling load established cost effectiveness of the heat absorbing lite to the low-emissivity system. For the glazing systems as a group, in cooling dominated climates, the relationship between the degree of heating requirement and severity of cooling load determines the optimum solution using either a reflective or a low-emissivity system.

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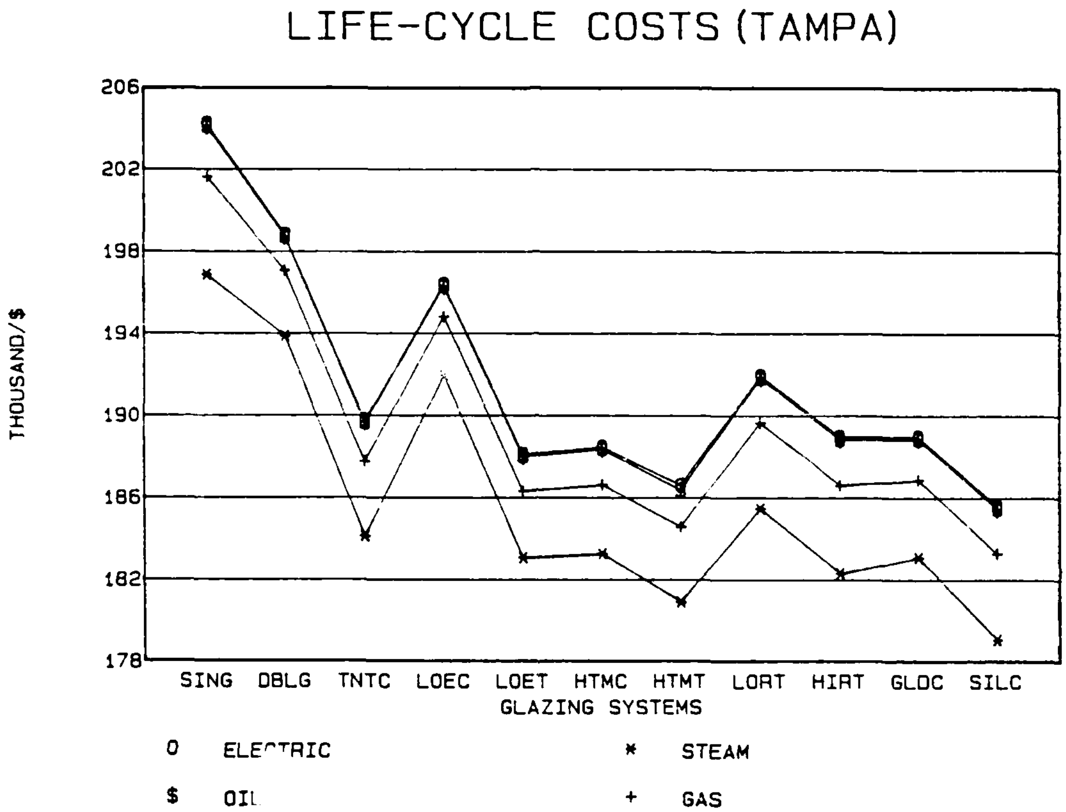

Figure 15: Total Life-Cycle Costs for Tampa, Florida. Refer to List of Symbols for definition of acronyms.

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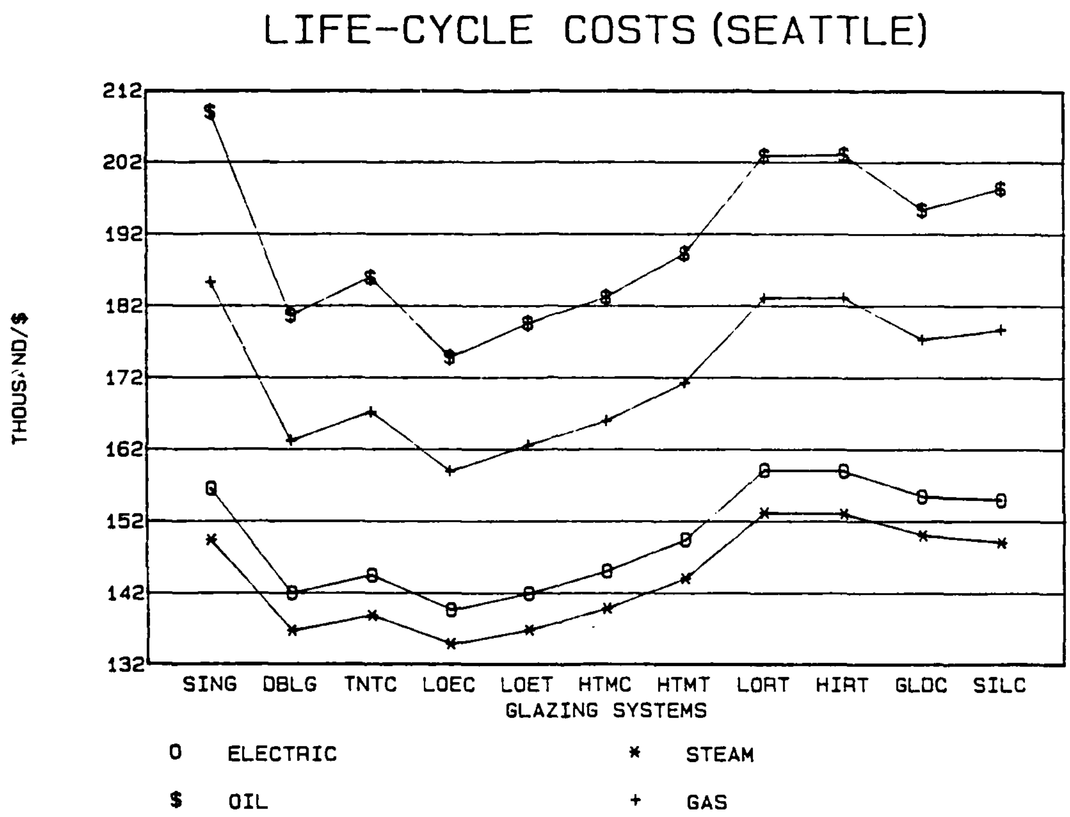

Figure 16: Total Life-Cycle Costs for Seattle, Washington. Refer to List of Symbols for definition of acronyms.

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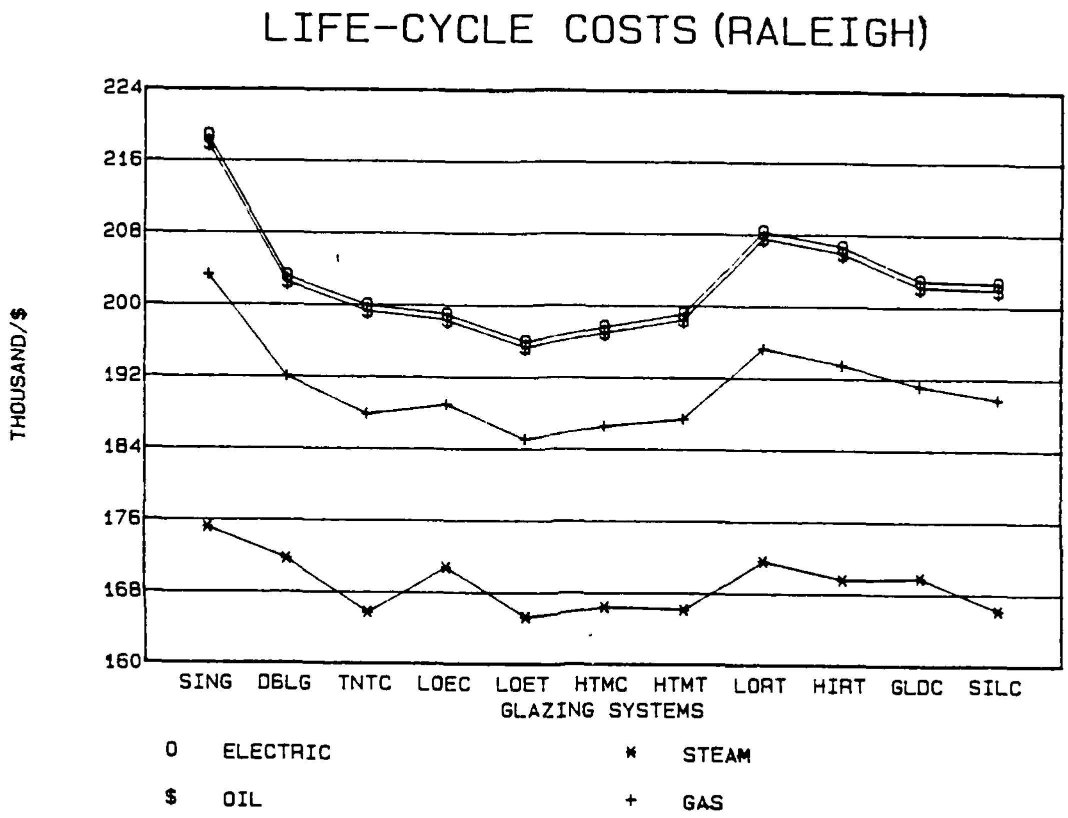

Figure 17: Total Life-Cycle Costs for Raleigh, North Carolina. Refer to List of Symbols for definition of acronyms.

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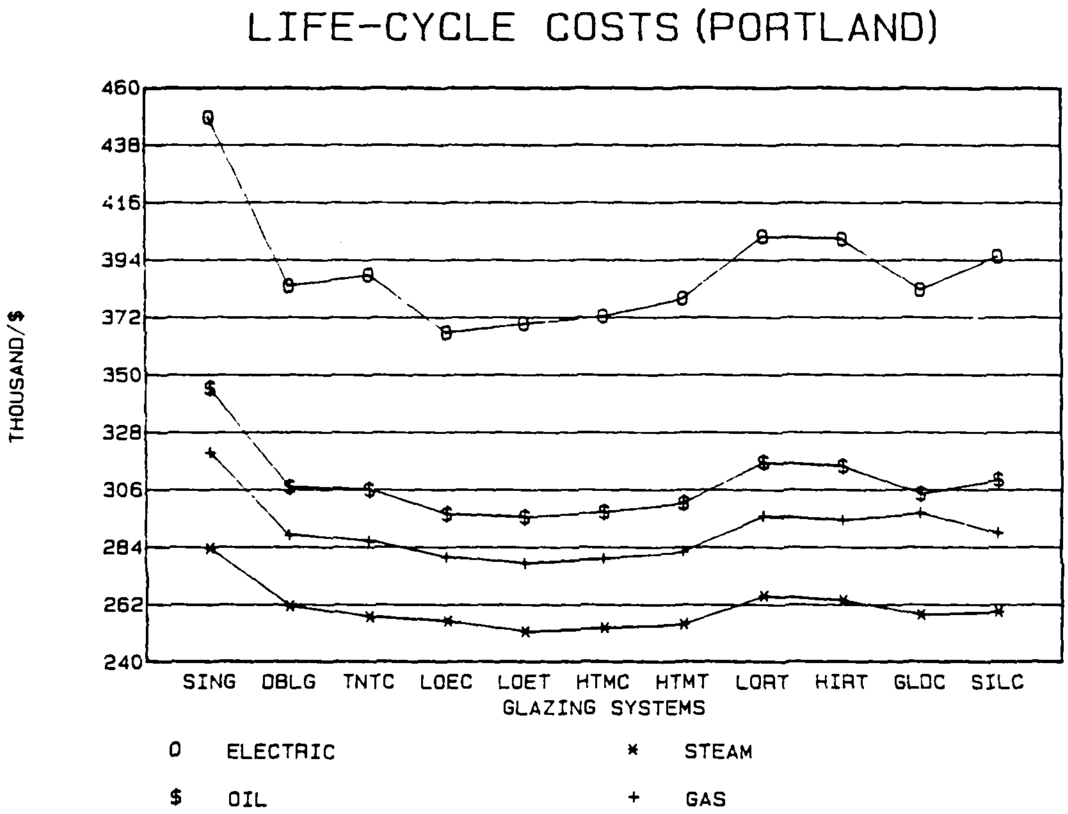

Figure 18: Total Life-Cycle Costs for Portland, Maine. Refer to List of Symbols for definition of acronyms.

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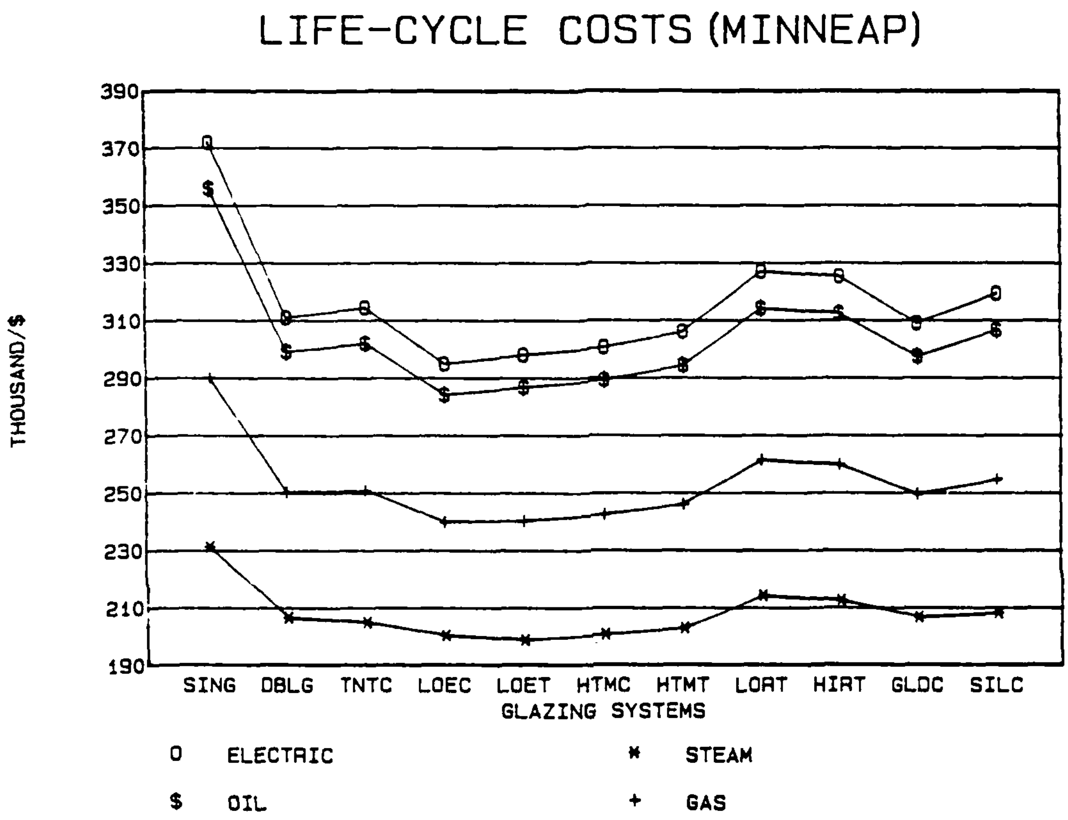

Figure 19: Total Life-Cycle Costs for Minneapolis, Minnesota. Refer to List of Symbols for definition of acronyms.

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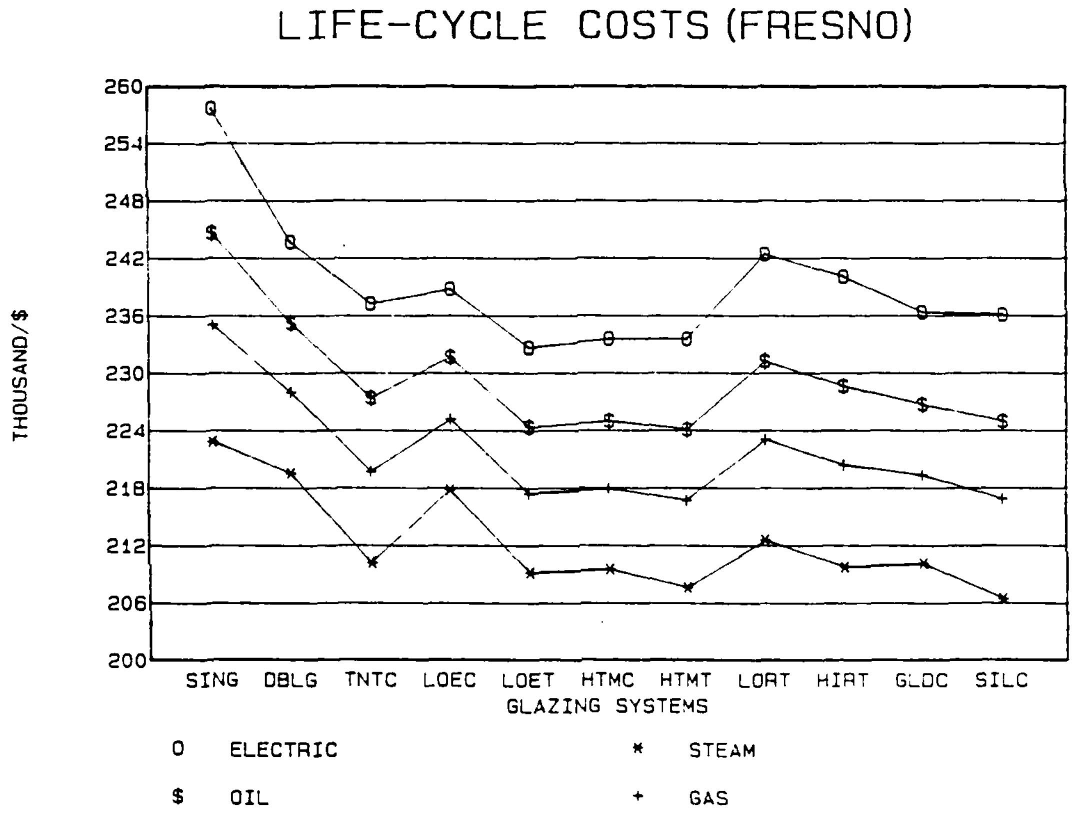

Figure 20: Total Life-Cycle Costs for Fresno, California. Refer to List of Symbols for definition of acronyms.

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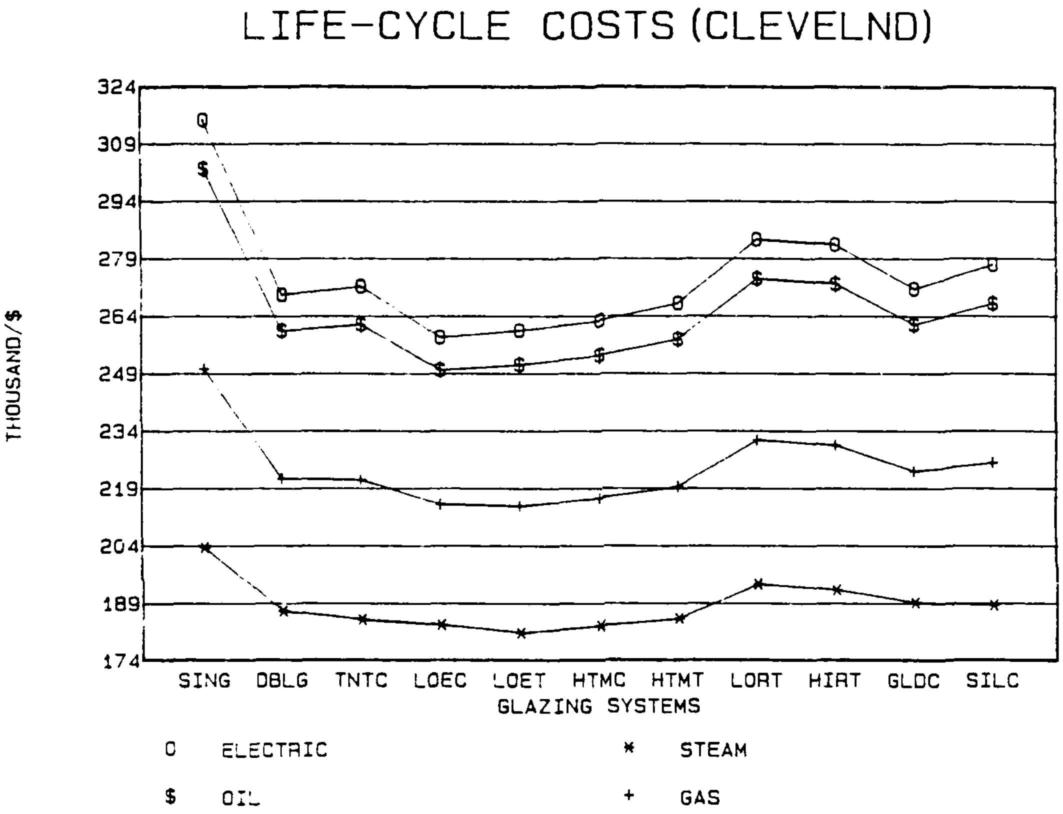

<u>Figure 21</u>: Total Life-Cycle Costs for Cleveland, Ohio. Refer to List of Symbols for definition of acronyms.

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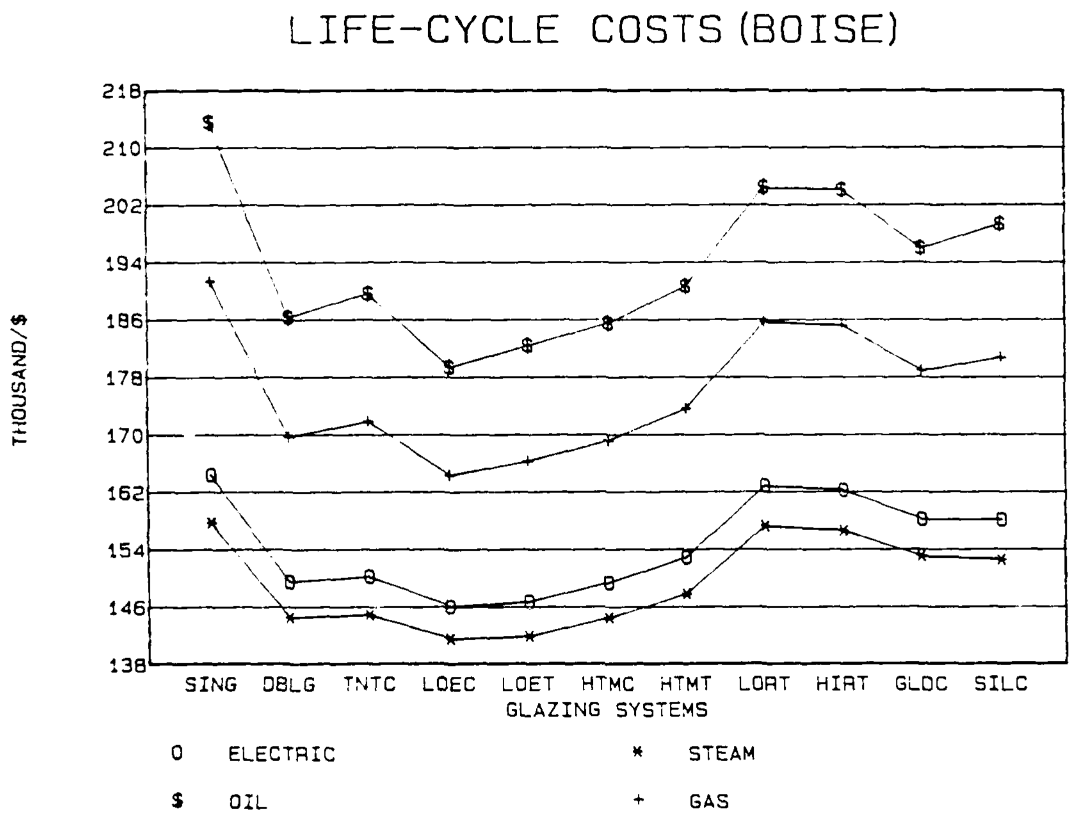

Figure 22: Total Life-Cycle Costs for Boise, Idaho. Refer to List of Symbols for definition of acronyms.

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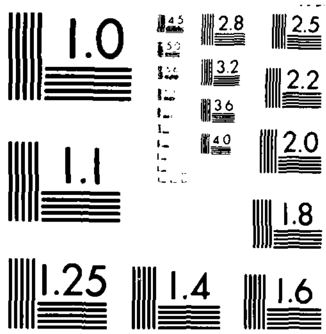

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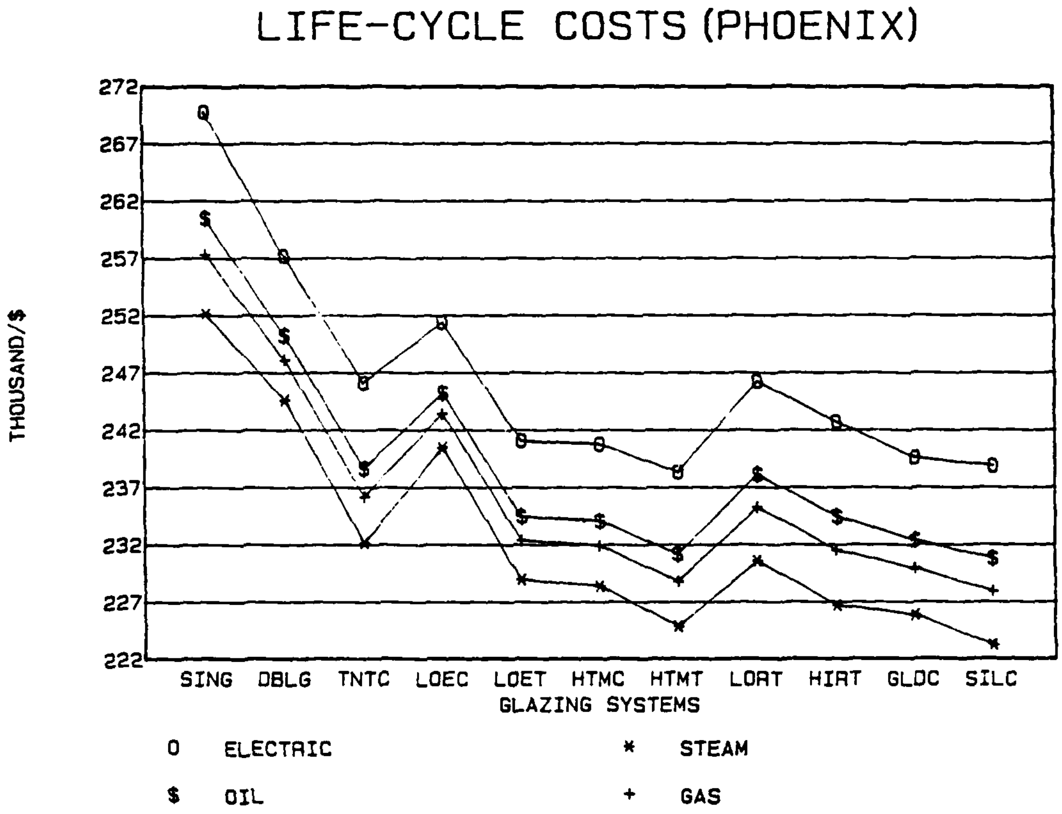

Figure 23: Total Life-Cycle Costs for Phoenix, Arizona. Refer to List of Symbols for definition of acronyms.

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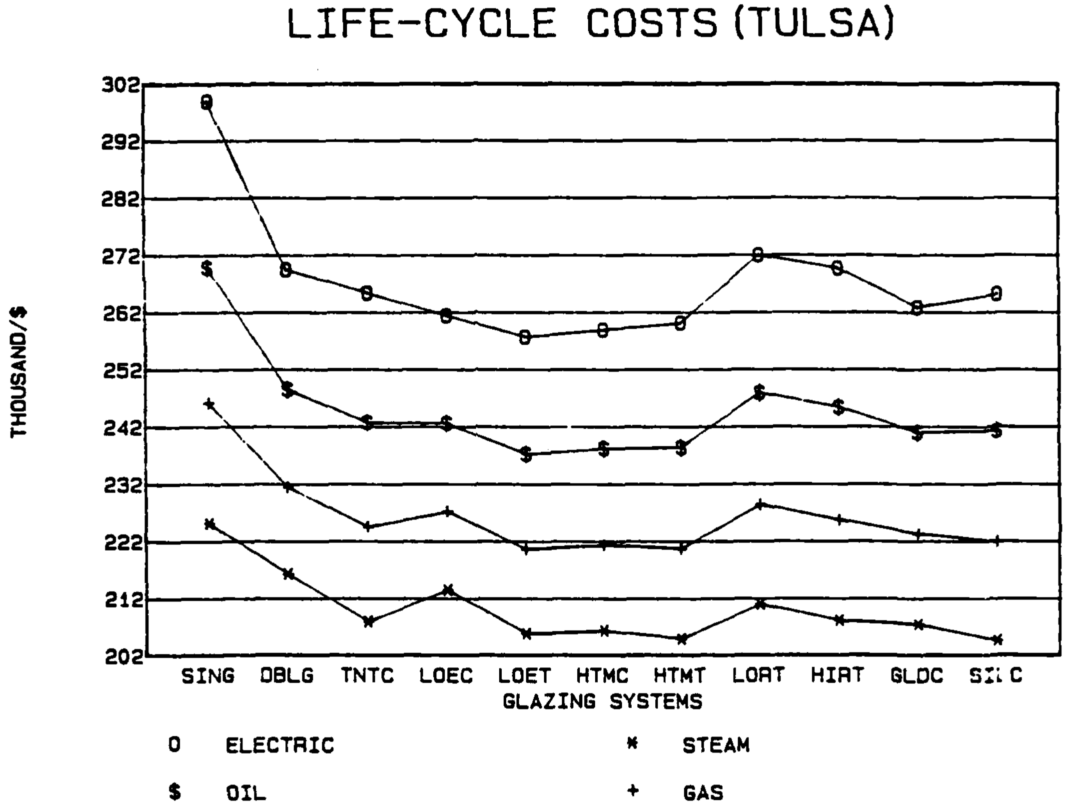

Figure 24: Total Life-Cycle Costs for Tulsa, Oklahoma. Refer to List of Symbols for definition of acronyms.

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Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Current procedures available for evaluating glazing performance, as a function of building energy requirements, suggest unreliable and cumbersome solutions in determining data of significant importance. Ineffeciencies in traditional steady state calculations enable a designer to precisely analyze only certain aspects of the total performance impact. Hour-by-hour computer simulations provide an accurate analysis but typically at a prohibitive cost and involving considerable time to accomplish.

Building designers have the task of evaluating numerous options in determining optimum solutions for new and retrofit construction projects. The designer should have the ability to independently assess glazing parameter effects on the cooling and heating components of a building. A procedure for examining glazing effects on component peaks should give the designer information for dealing with equipment sizing and in analyzing energy demand strategies. These procedures should be easily understood and accomplished, yielding dependable results for varying situations. A comparative performance and economic analysis of present state-of-the-art glazing systems should give the building designer insight into important performance

capabilities applicable for several climatic regions in this country.

6.2 Conclusions

Of primary importance is the ability for a building designer to be able to assess the effects that glazing characteristics have on the energy performance of the building. The degree of energy that is squandered through fenestration devices makes this issue of paramount importance to efficient-energy conscious design.

Statistical procedures, through multiple regression analysis, can determine the correlation between building energy requirements, glazing system parameters and significant climatic variables. Predictor equations can be developed enabling designers to use simple algebraic expressions to accurately optimize glazing performance strategies.

The development of an integrated economic analysis can offer guidance to designers by allowing evaluation of performance coupled with detailed energy and investment costs. Economic results indicate that low-emissivity systems provide optimum performance for most climatic regions, over a total life-cycle cost basis. The exception to this is for buildings located in extreme cooling load dominated locations where the solar energy rejection capabilities of high reflective systems are advantageous.

The glazing performance strategies accomplished should be a useful design tool provided they are attempted within the context of the assumptions used in this study. Significant deviations from occupancy patterns and building characteristics have not been validated. Results attained with these procedures should be used for comparative analysis between alternative systems. Specific quantities should be related as a proportionate relationship to other systems, rather than actual values.

6.3 Recommendations for Future Study

The data base generated for this study should be expanded to include additional parameters depicting a wider variation of climatic regions, aperture ratios and glazing systems in single or triple pane configurations. Additionally, expansion of the data base to include additional building types and useage patterns would further increase the applicability to other design challenges.

Statistical procedures should provide a more diverse range of generalized predictor equations. Regression procedures could integrate regional energy costs and system pricing to enable evaluation of performance variations including economic differences. Optimum performance parameters could be predicted to aid glazing manufacturers in adjusting selective transmittance characteristics for critical spectral ranges.

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Appendix A

BUILDING MODEL CHARACTERISTICS

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Table 13: Architectural Description

*Building Type	Two-Story Free-Standing Medium Weight Construction Unconditioned Plenum	
*Building Use	Commercial Office Space	
*Floor Area	50,000 ft^2, divided into seven conditioned zones	
*Volume	707,200 ft^3 total space	
*Floor	Carpet with pad on four-inch concrete slab	
*Fenestration	Windows set back eight inches from exterior wall, draperies modelled on operational schedule based on occupancy	
*Lighting	2.5 watts/ft^2 general 0.5 watts/ft^2 task lighting lighting power dissipated as heat to interior space	
*Equipment	0.5 watts/ft^2 general	
*Computer Equipment	5.2 watts/ft^2	
*Occupancy	371 people, 8 am - 5 pm, Mon - Fri, all yr ex/holdys	
*Thermostatic Settings	Occupied	Unoccupied
Winter	73	55
Summer	73	85
*Infiltration	0.6 air changes per hour	

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Table 14: Envelope Details

Envelope Details Component	Thermal Conductance ($Btu/h*ft^2*F$)	Layer
*********	******* ***********	*****
Floor	0.05	Carpet/Pad Concrete Slab Rigid Insulation
Wall	0.089	Face Brick Airspace Rigid Insulation Masonry Block Air Space Gypsum Drywall
Roof	0.106	Built-up Roof Rigid Insulation Metal Roof Deck

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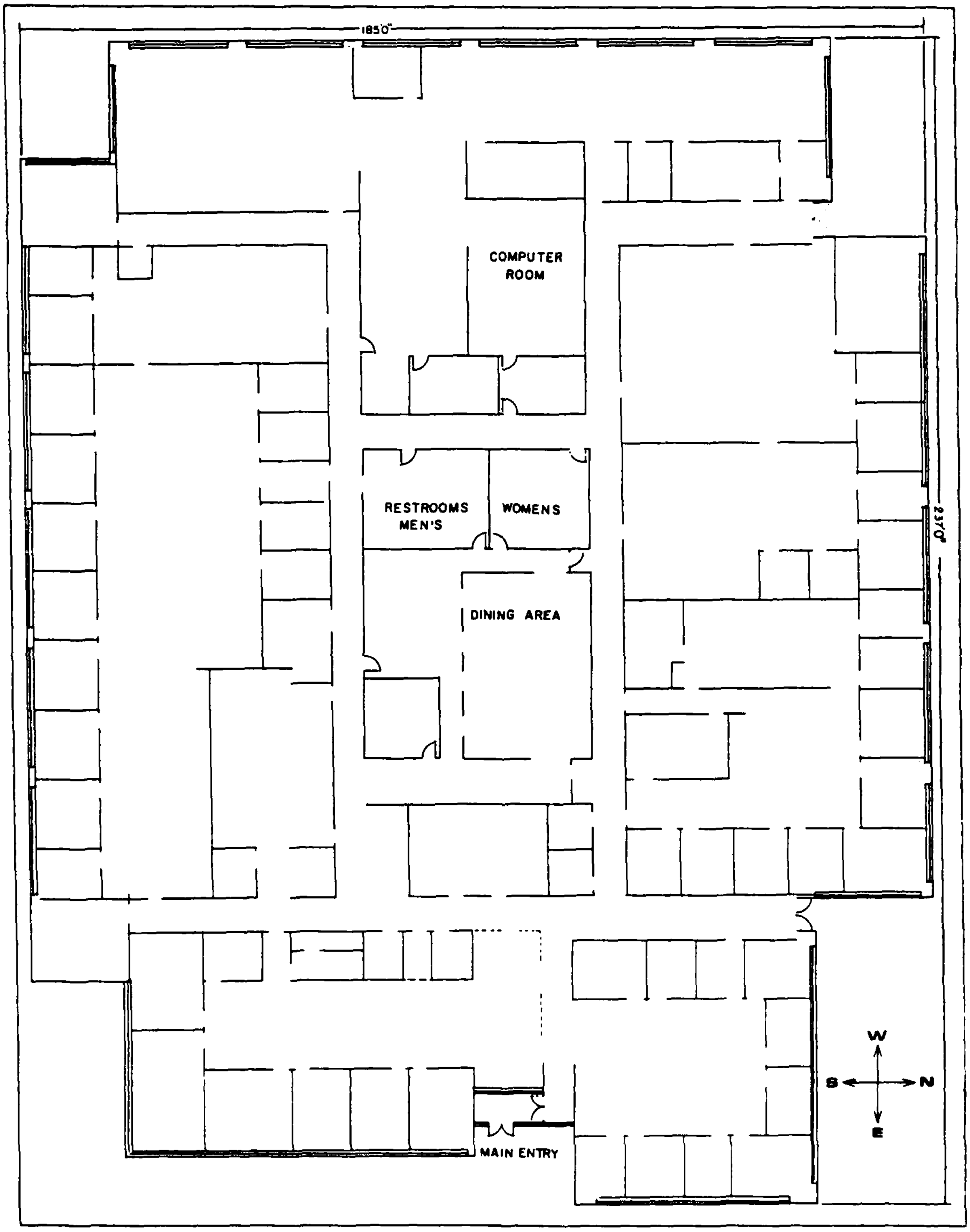

Figure 25: Floor Plan of Research Building. Low-Rise Commercial Office Building. Plan Not To Scale.

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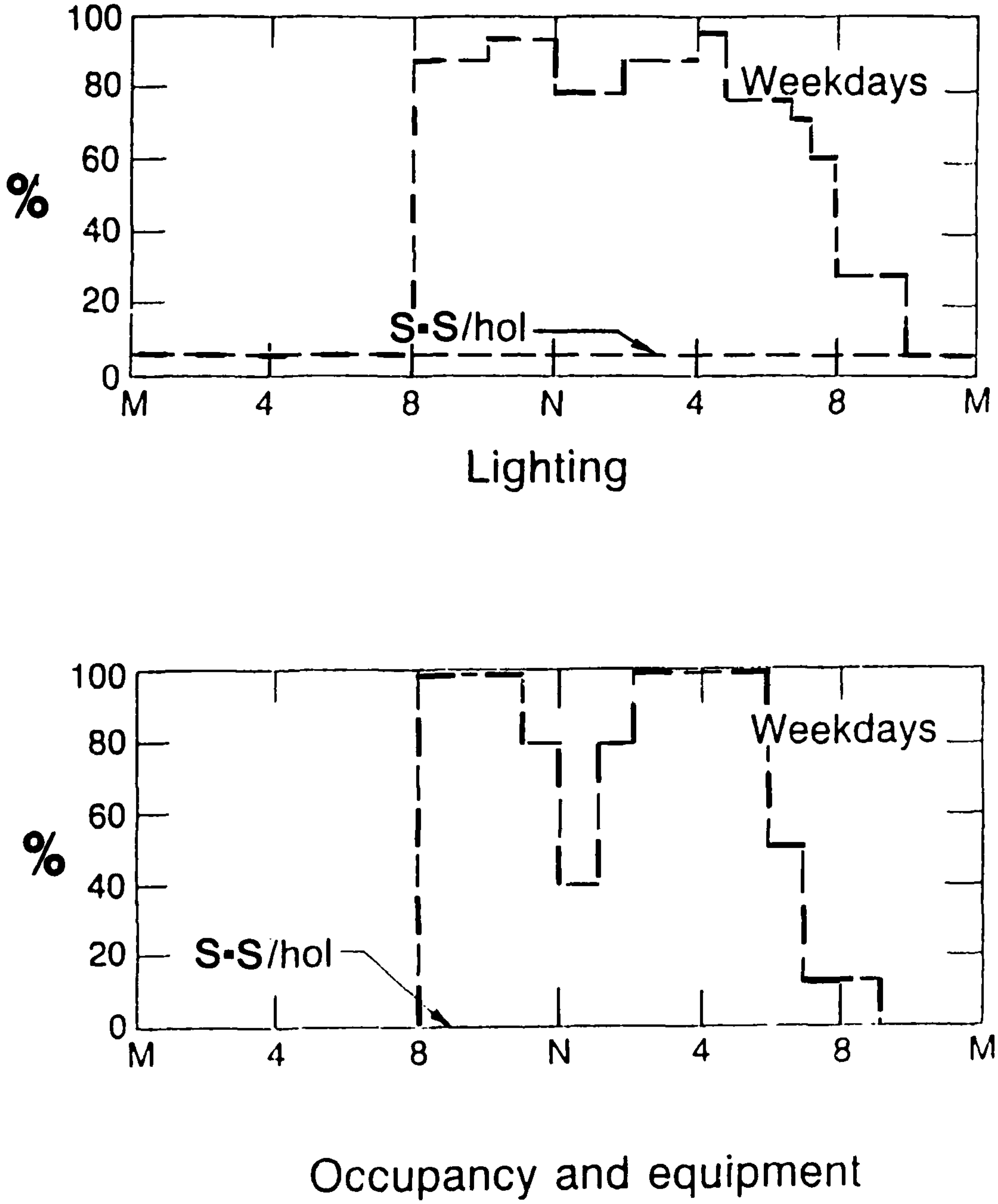

Figure 26: Building Operating Schedules. Represents internal lighting, occupancy and equipment schedules for research building. Not valid for computer equipment.

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Appendix B

MULTIPLE REGRESSION RESIDUAL PLOTS

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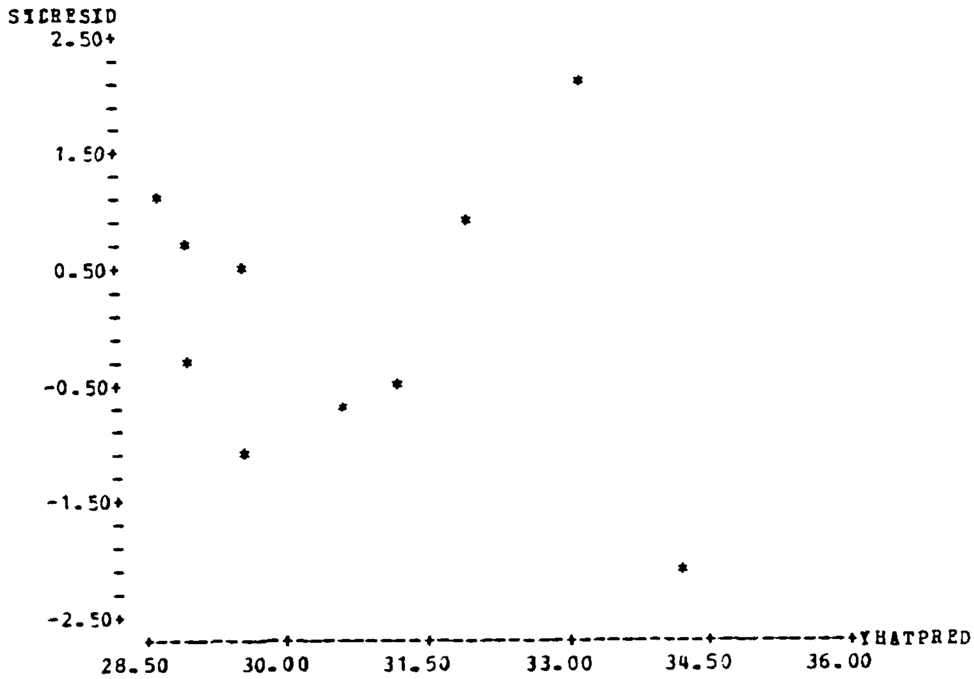

Figure 27: Cooling Load for Tampa, Florida

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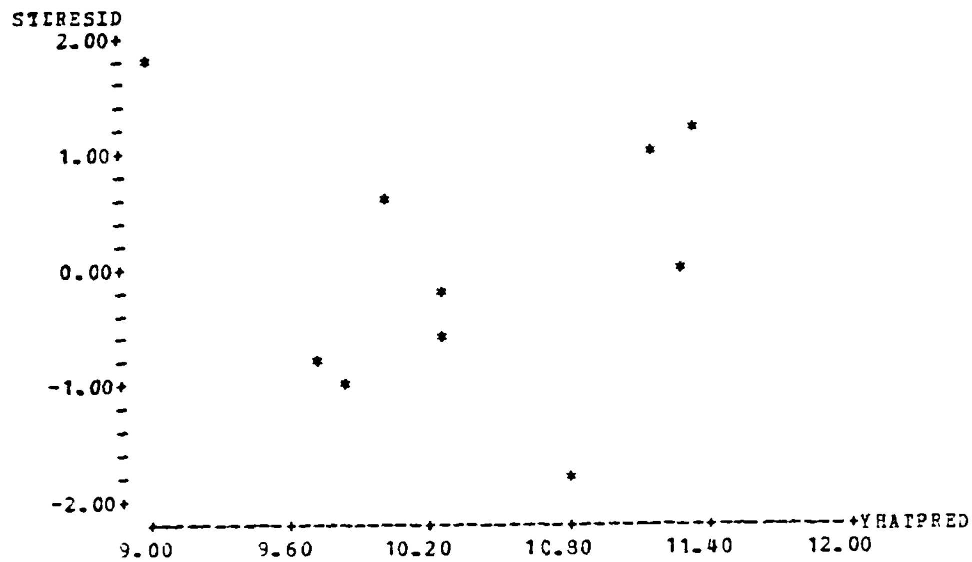

Figure 54: Heating Load for Boise, Idaho

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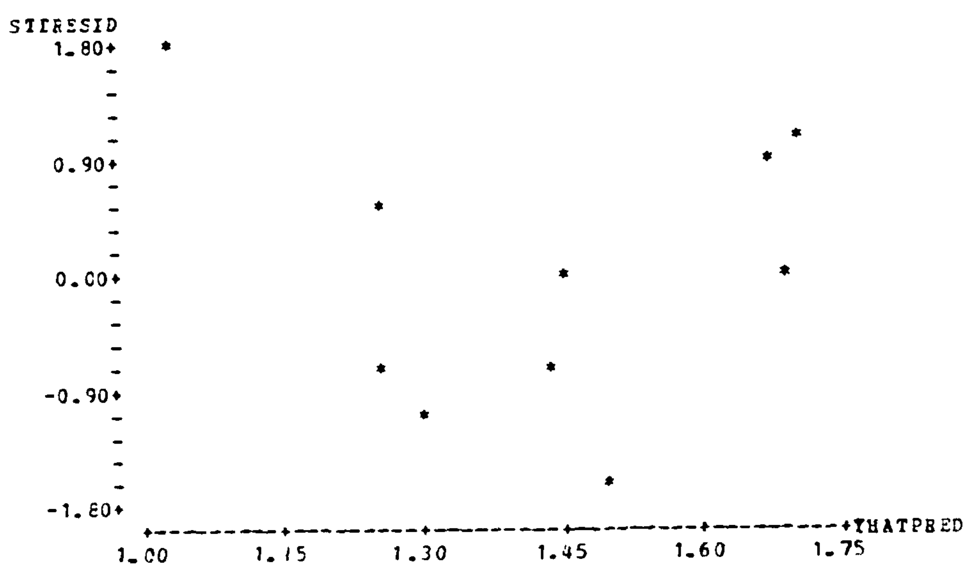

Figure 55: Heating Load for Phoenix, Arizona

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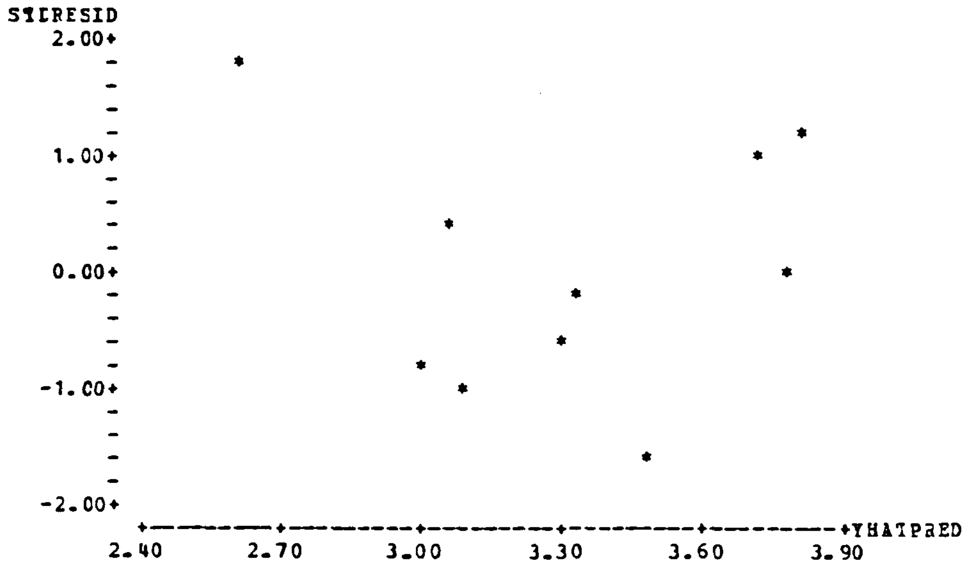

Figure 52: Heating Load for Fresno, California

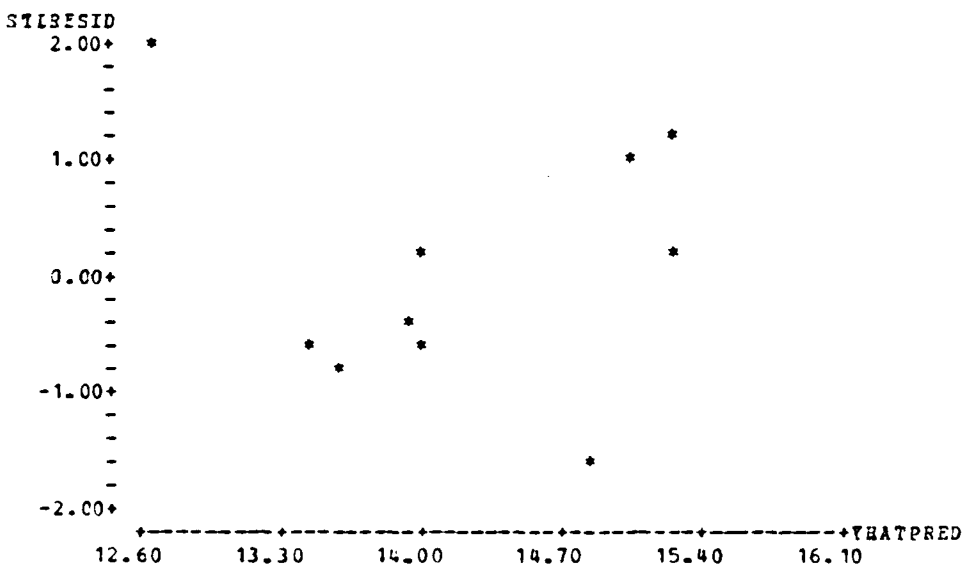

Figure 53: Heating Load for Cleveland, Ohio

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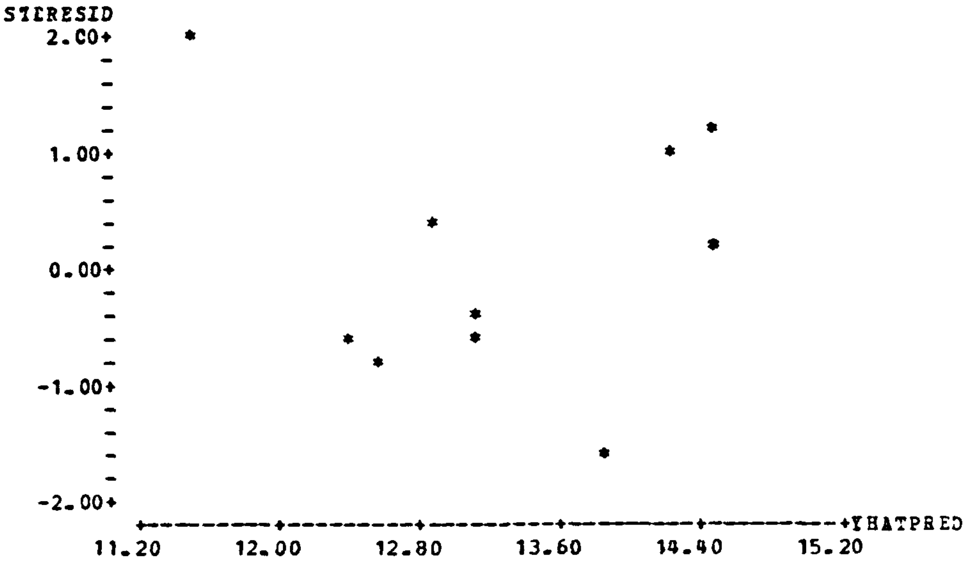

Figure 50: Heating Load for Portland, Maine

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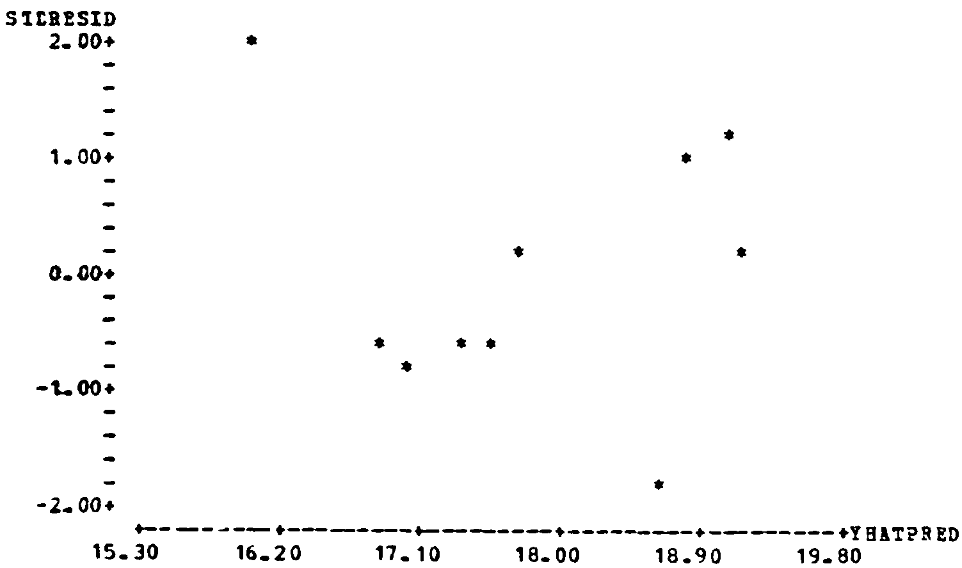

Figure 51: Heating Load for Minneapolis, Minnesota

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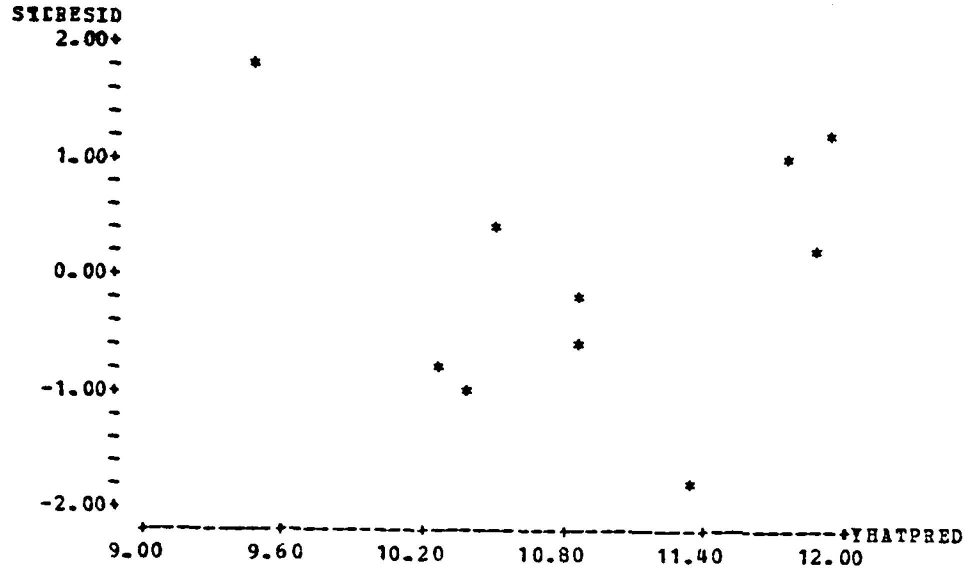

Figure 48: Heating Load for Seattle, Washington

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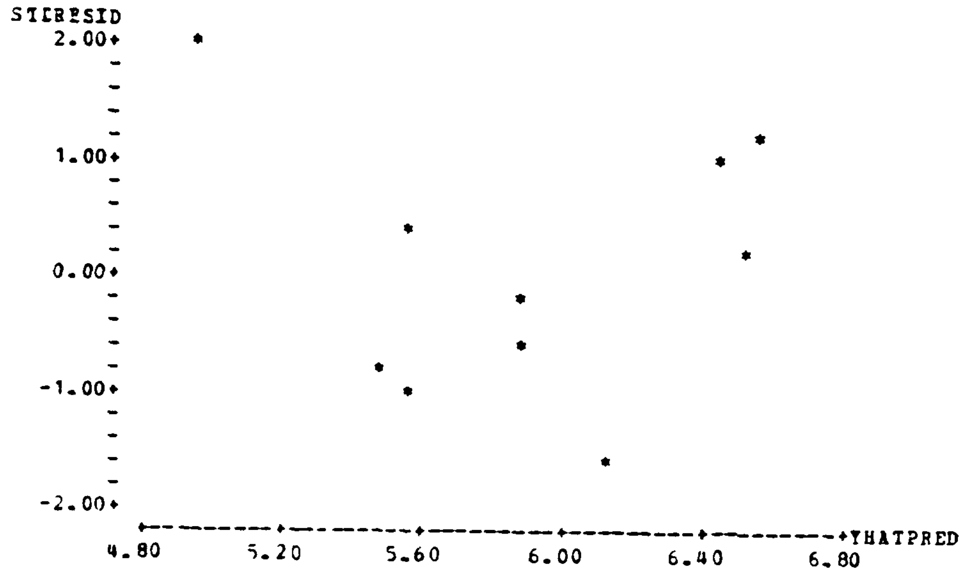

Figure 49: Heating Load for Raleigh, North Carolina

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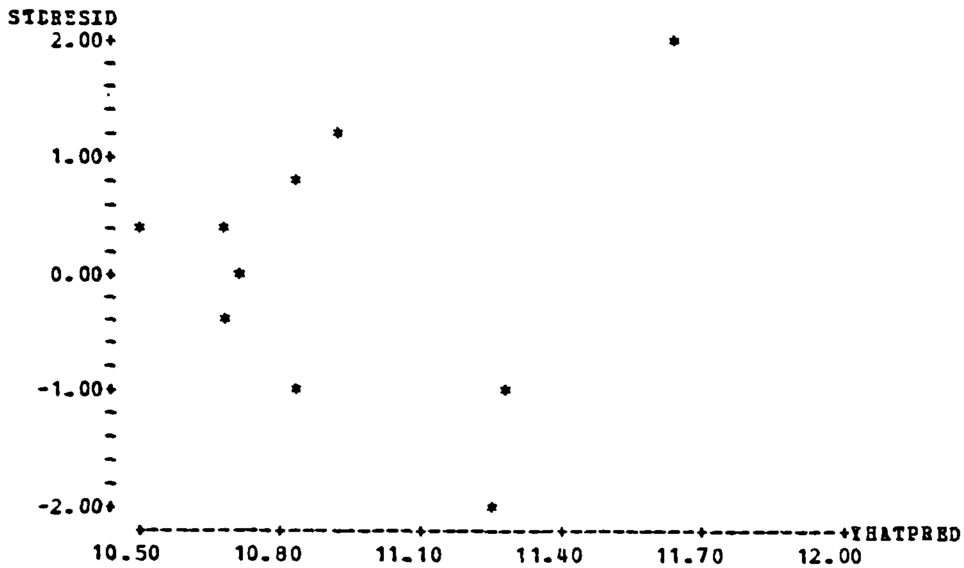

Figure 46: Cooling Peak for Tulsa, Oklahoma

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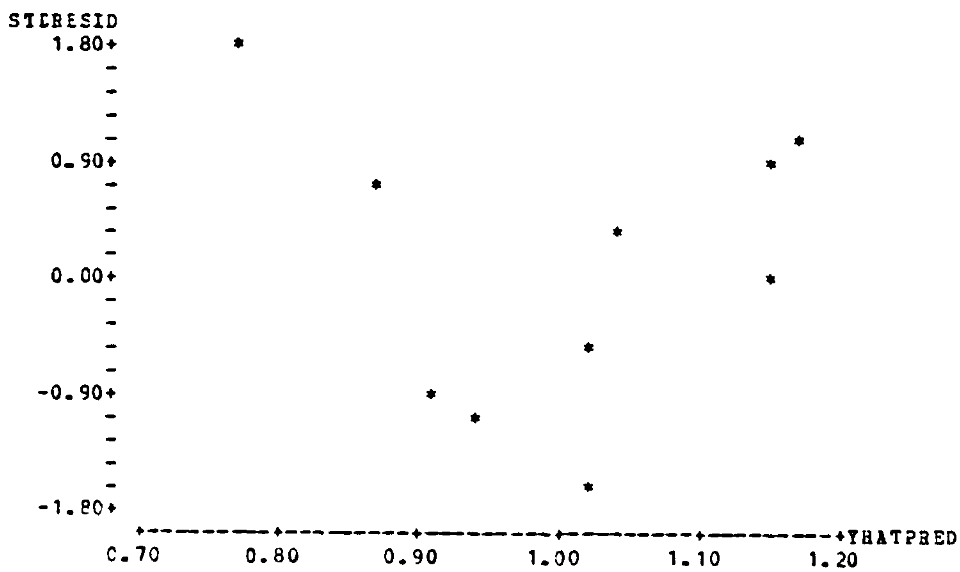

Figure 47: Heating Load for Tampa, Florida

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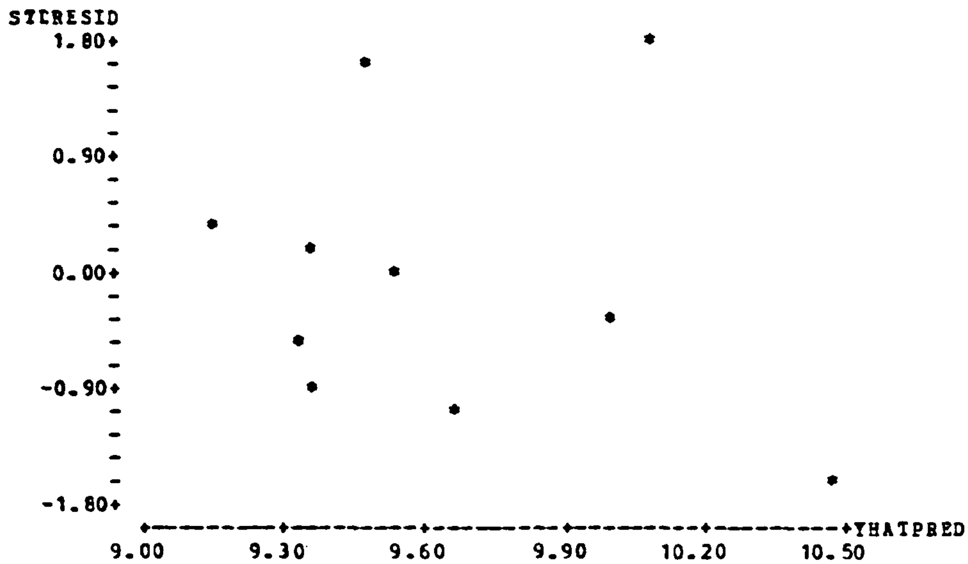

Figure 44: Cooling Peak for Boise, Idaho

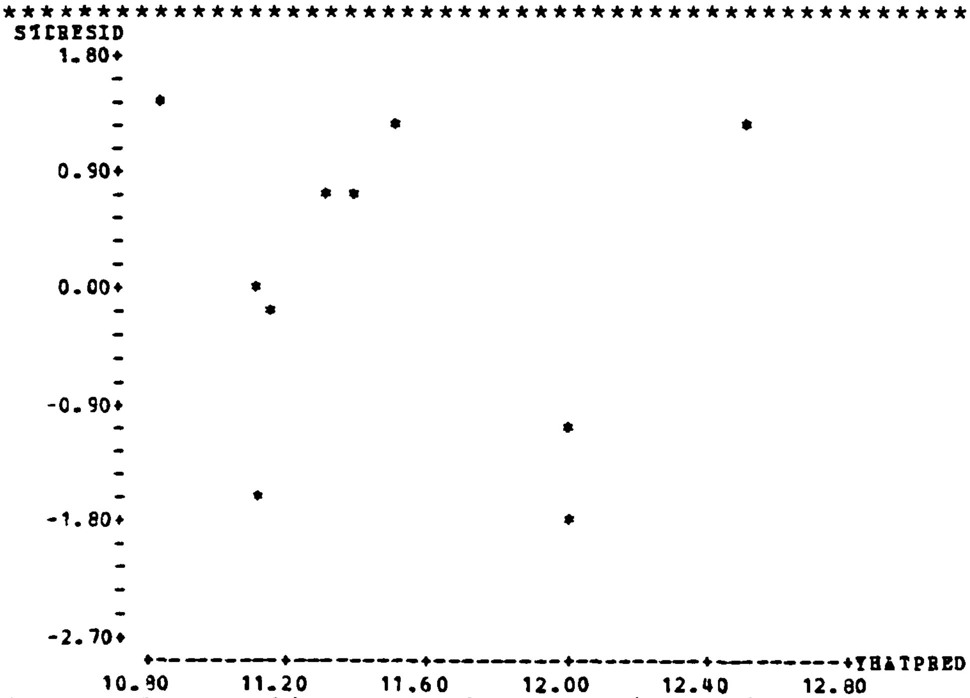

Figure 45: Cooling Peak for Phoenix, Arizona

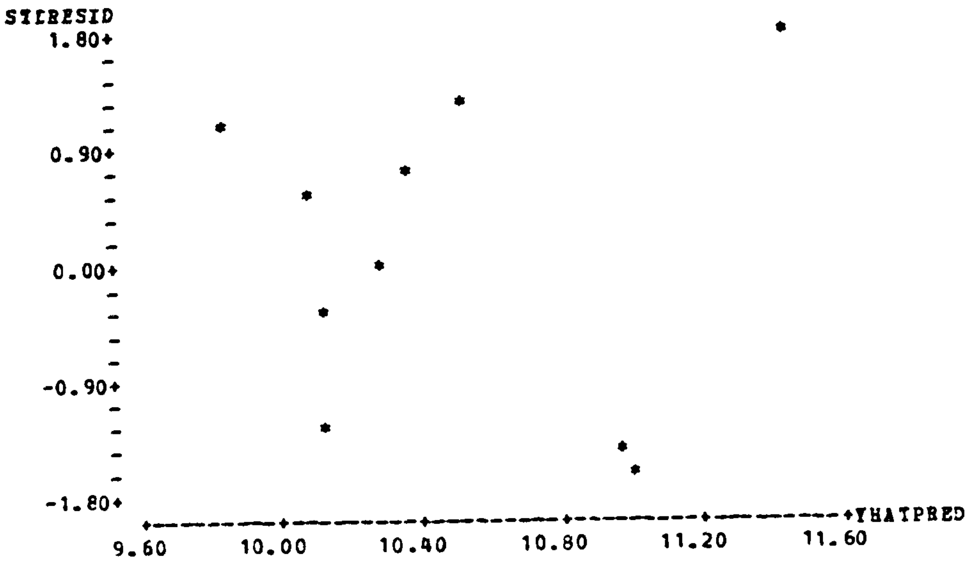

Figure 42: Cooling Peak for Fresno, California

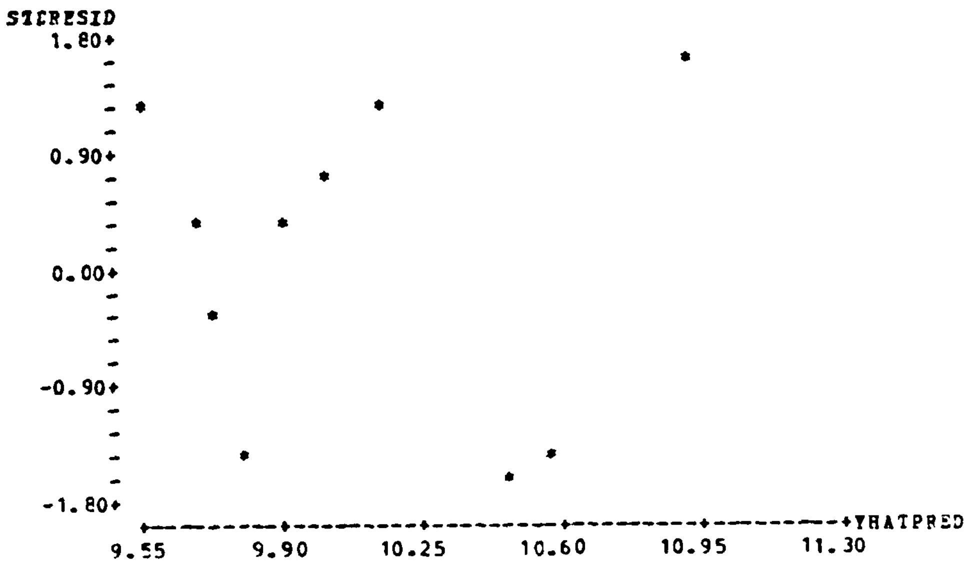

Figure 43: Cooling Peak for Cleveland, Ohio

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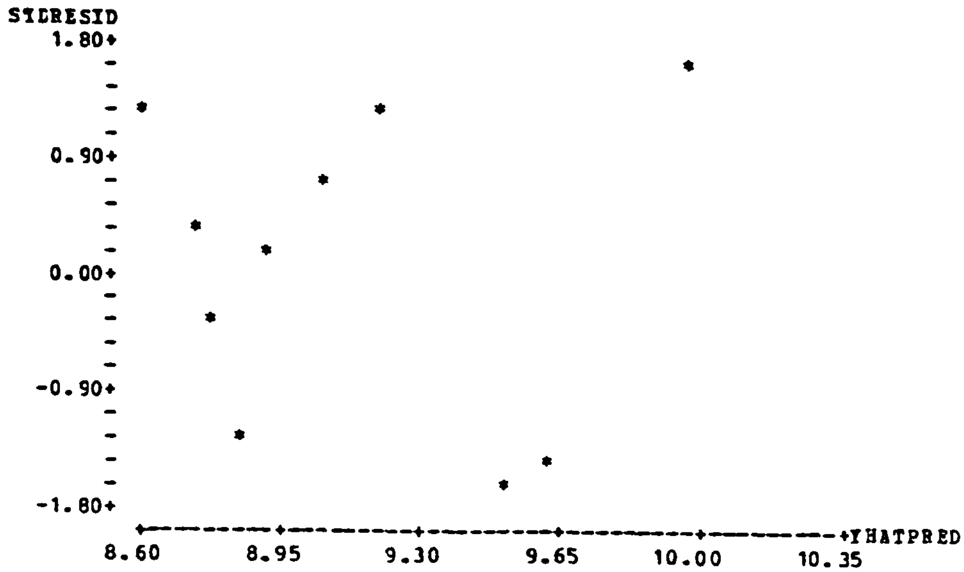

Figure 40: Cooling Peak for Portland, Maine

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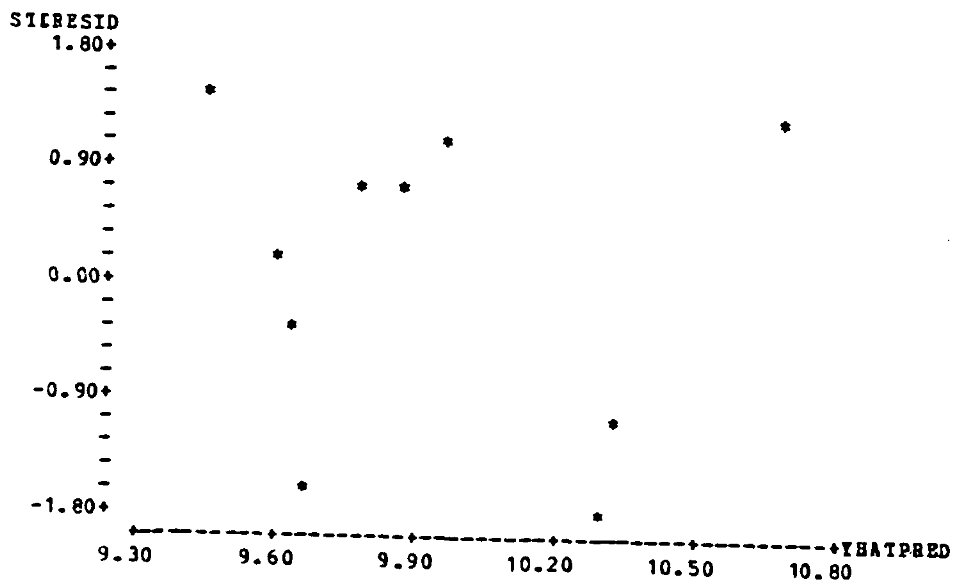

Figure 41: Cooling Peak for Minneapolis, Minnesota

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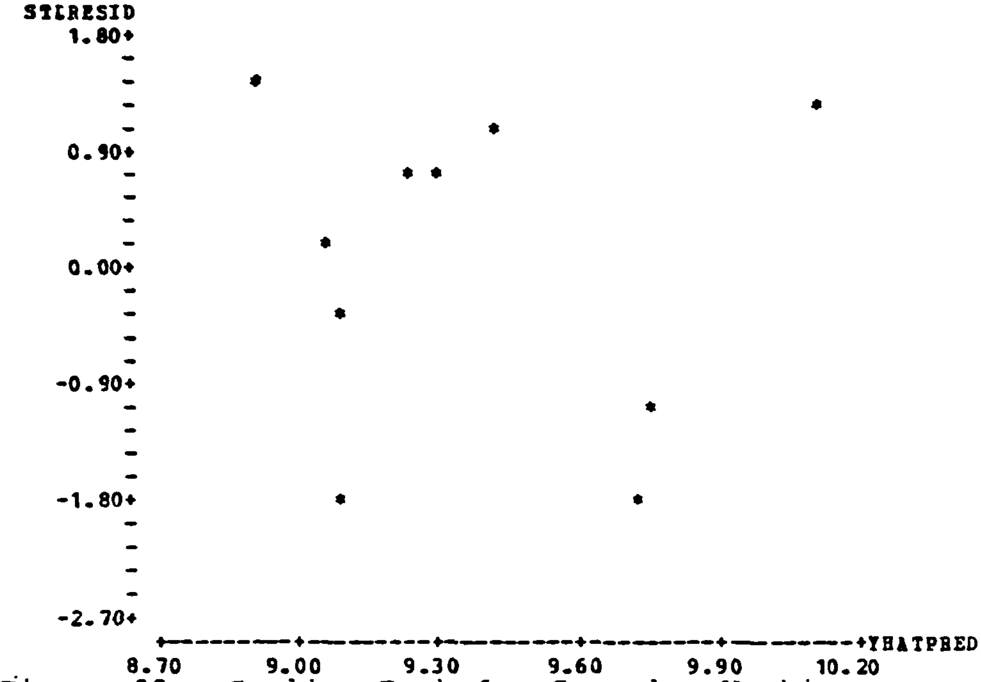

Figure 38: Cooling Peak for Seattle, Washington

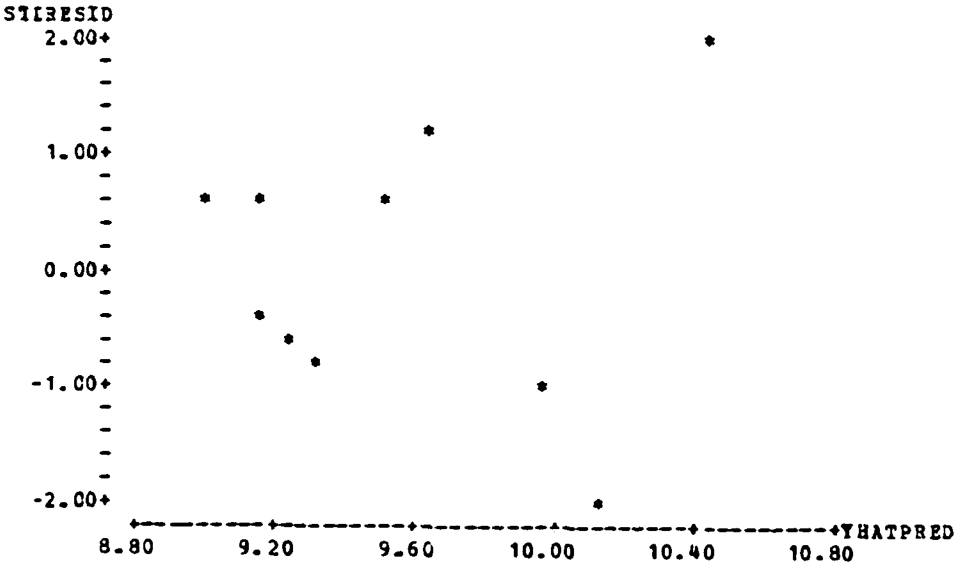

Figure 39: Cooling Peak for Raleigh, North Carolina

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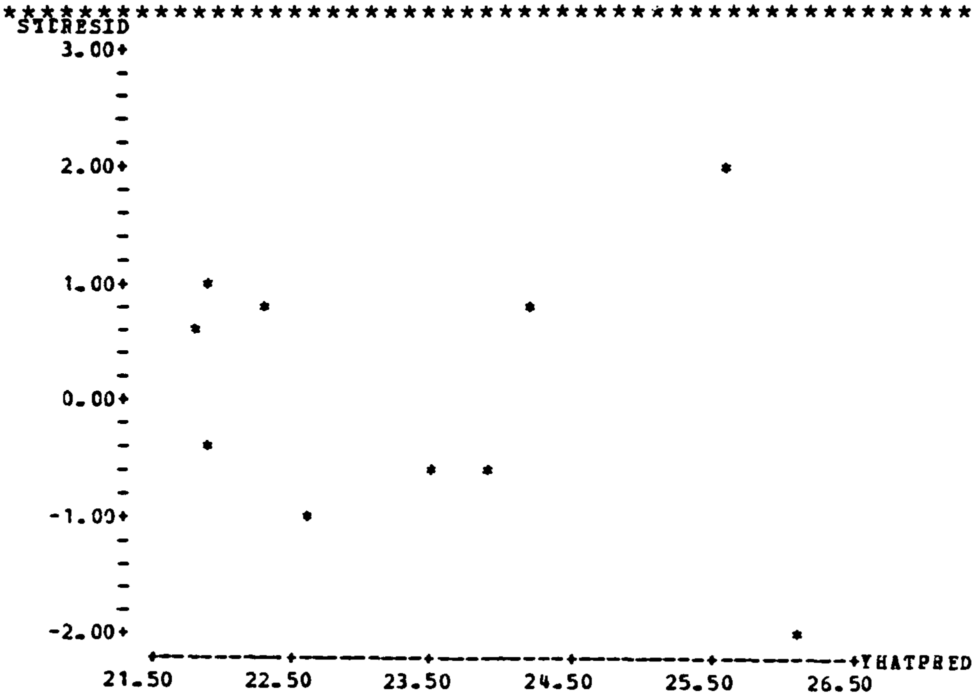

Figure 36: Cooling Load for Tulsa, Oklahoma

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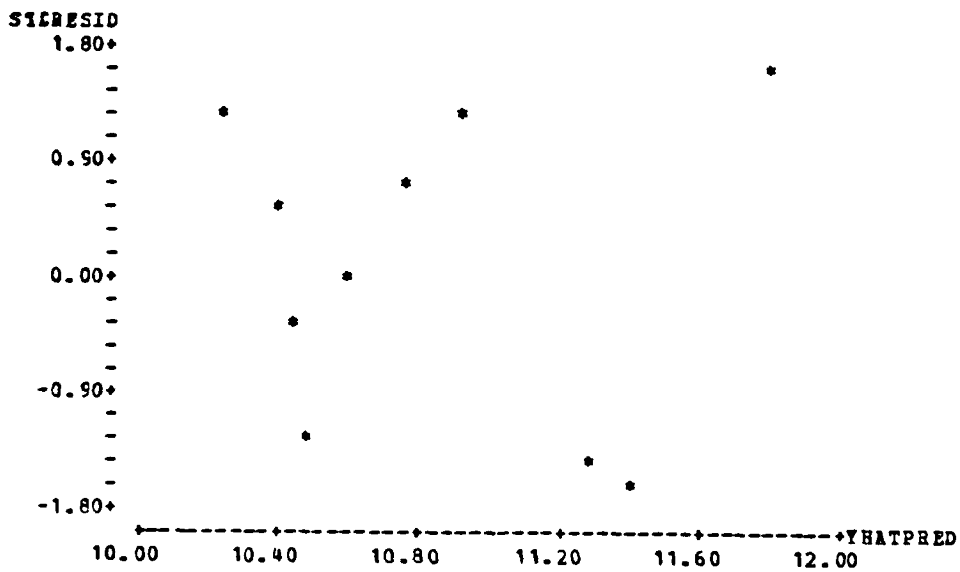

Figure 37: Cooling Peak for Tampa, Florida

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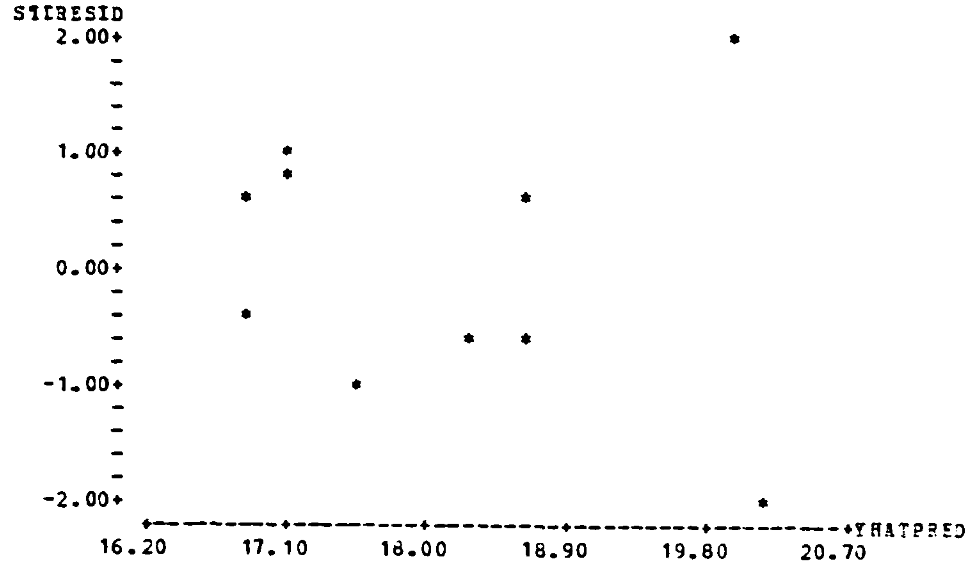
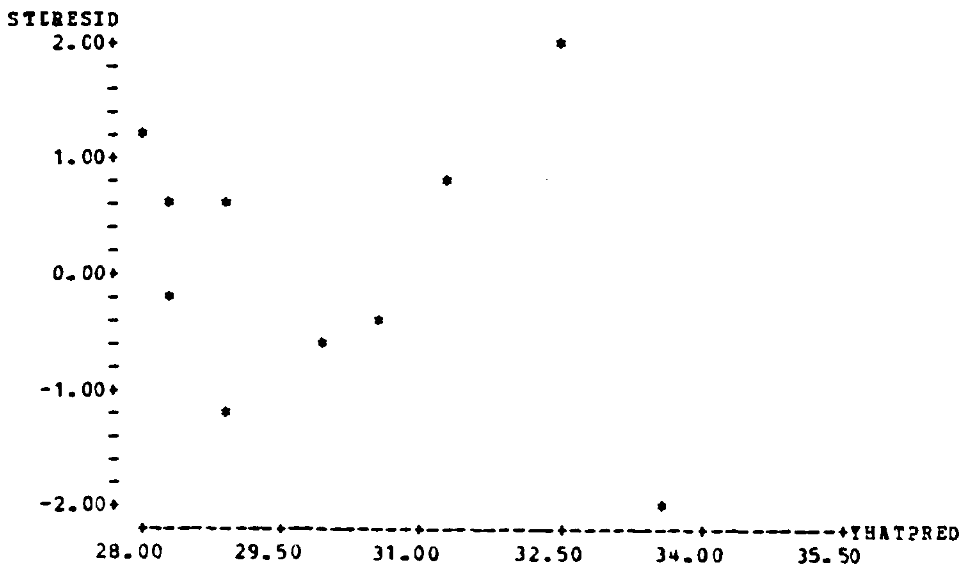


<u>Figure 34</u>: Cooling Load for Boise, Idaho



<u>Figure 35</u>: Cooling Load for Phoenix, Arizona

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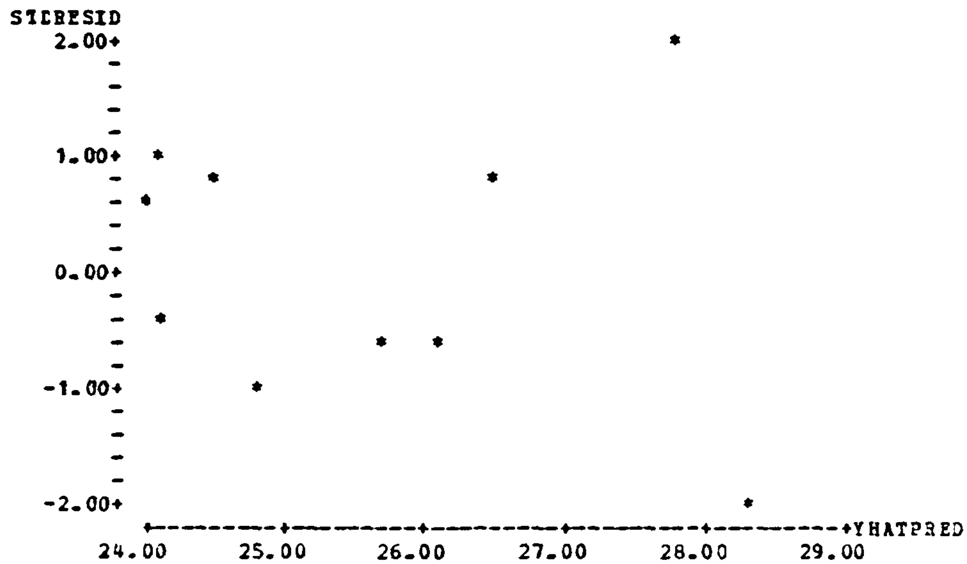

Figure 32: Cooling Load for Fresno, California

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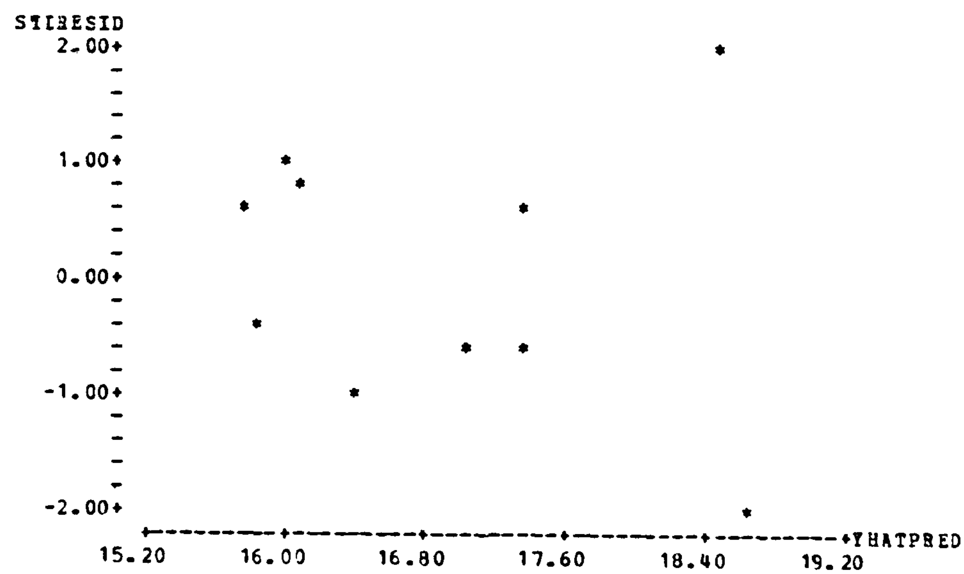

Figure 33: Cooling Load for Cleveland, Ohio

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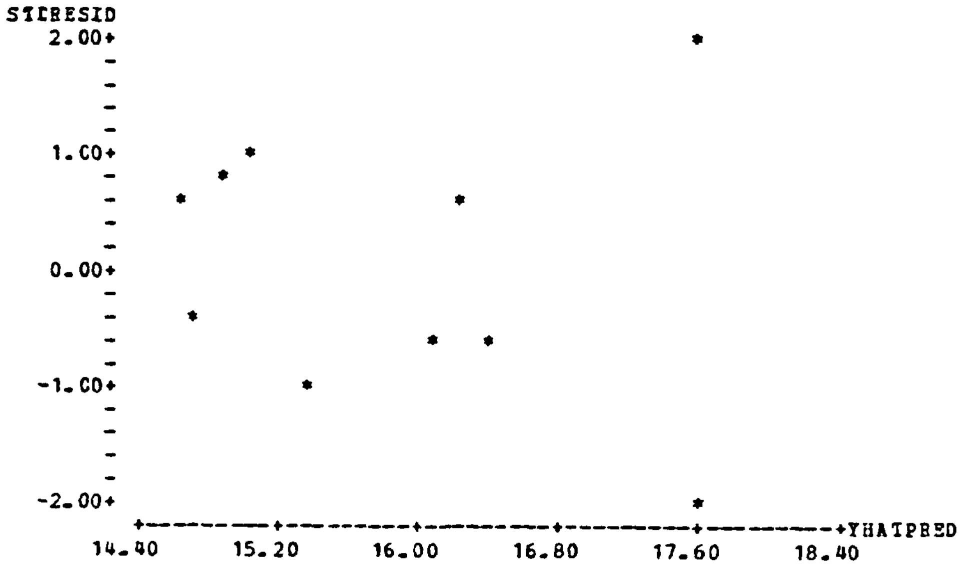

Figure 30: Cooling Load for Portland, Maine

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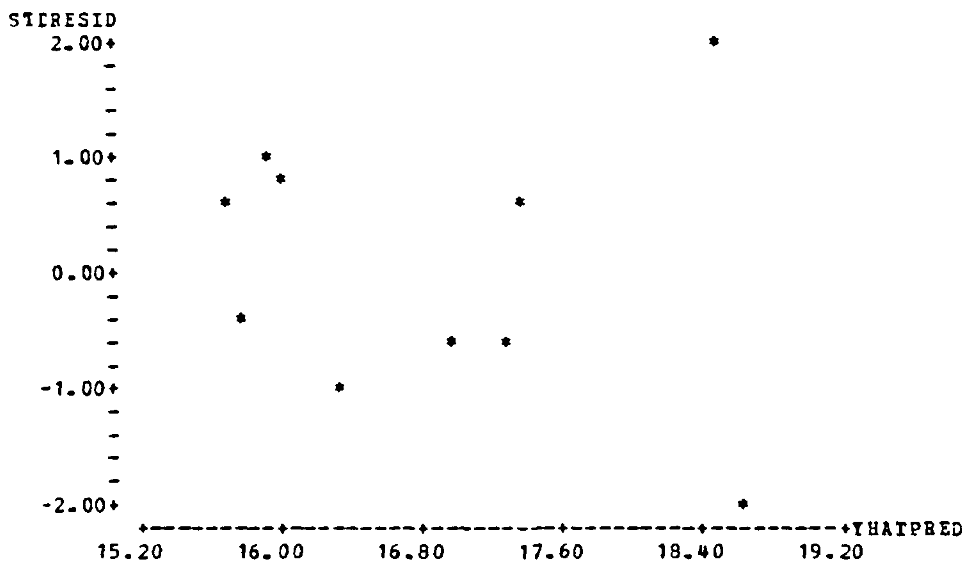

Figure 31: Cooling Load for Minneapolis, Minnesota

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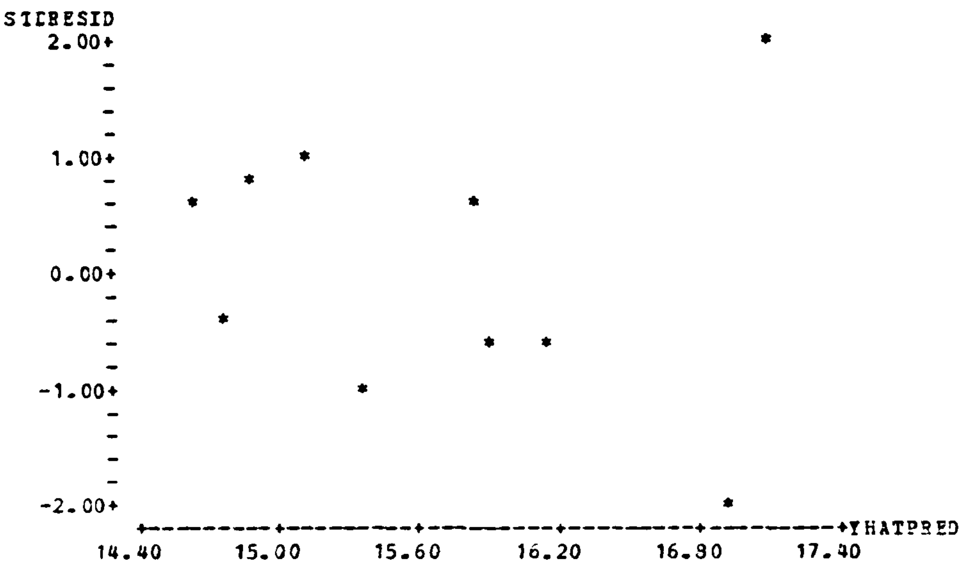

Figure 28: Cooling Load for Seattle, Washington

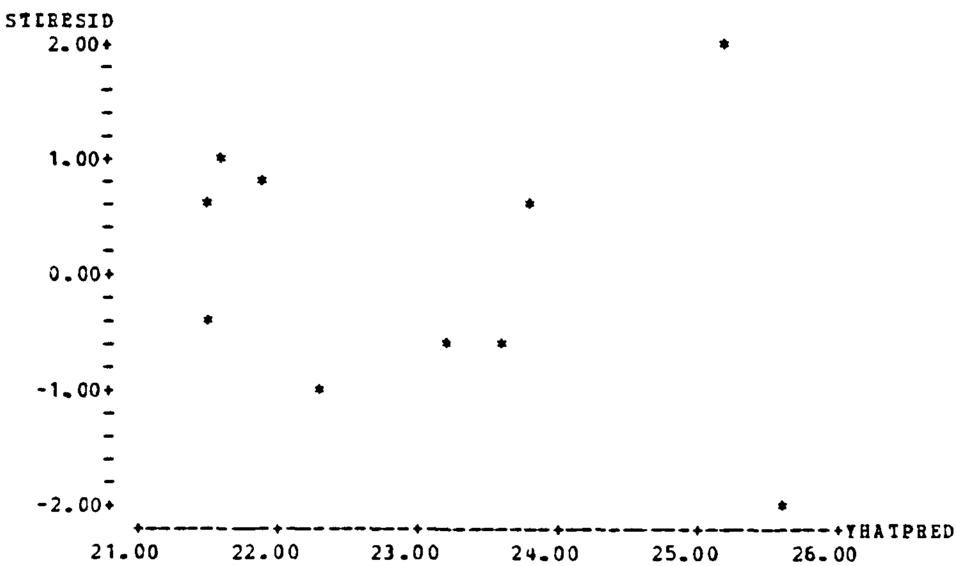

Figure 29: Cooling Load for Raleigh, North Carolina

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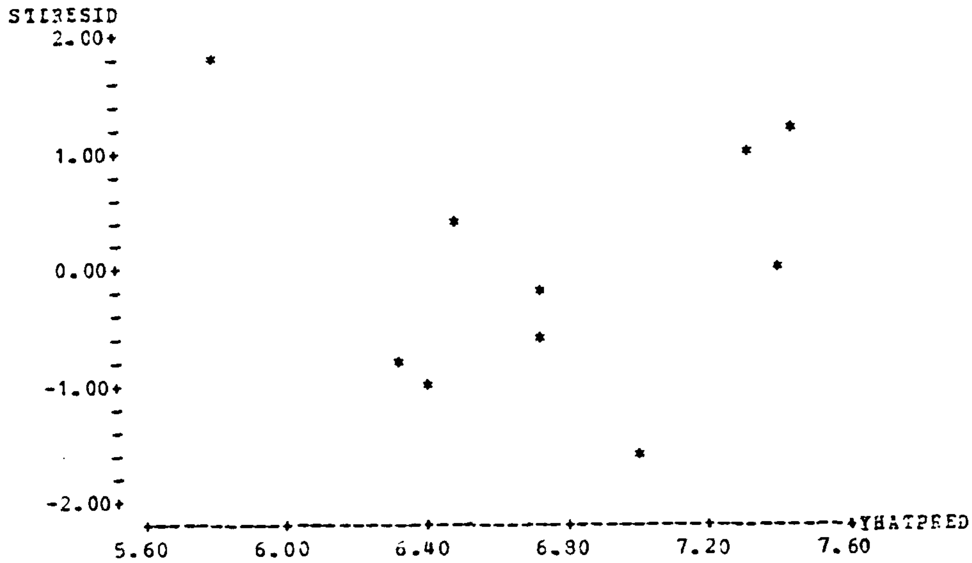

Figure 56: Heating Load for Tulsa, Oklahoma

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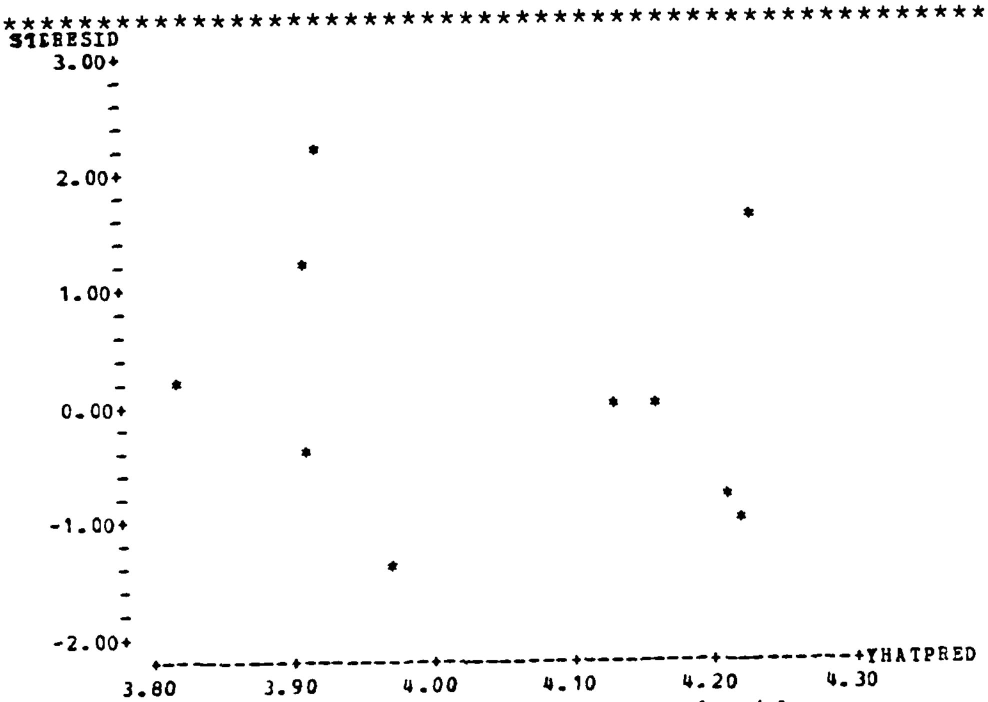

Figure 57: Heating Peak for Tampa, Florida

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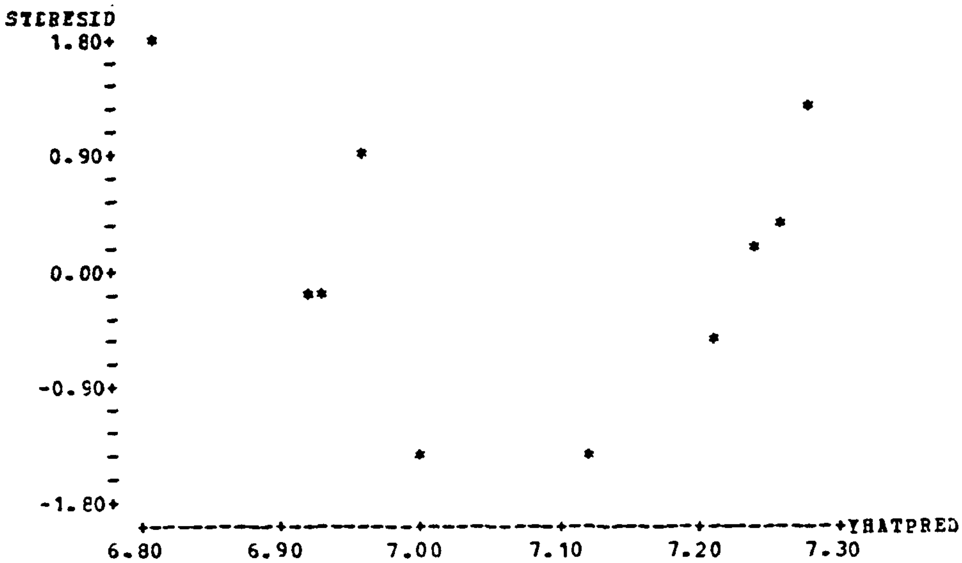

Figure 58: Heating Peak for Seattle, Washington

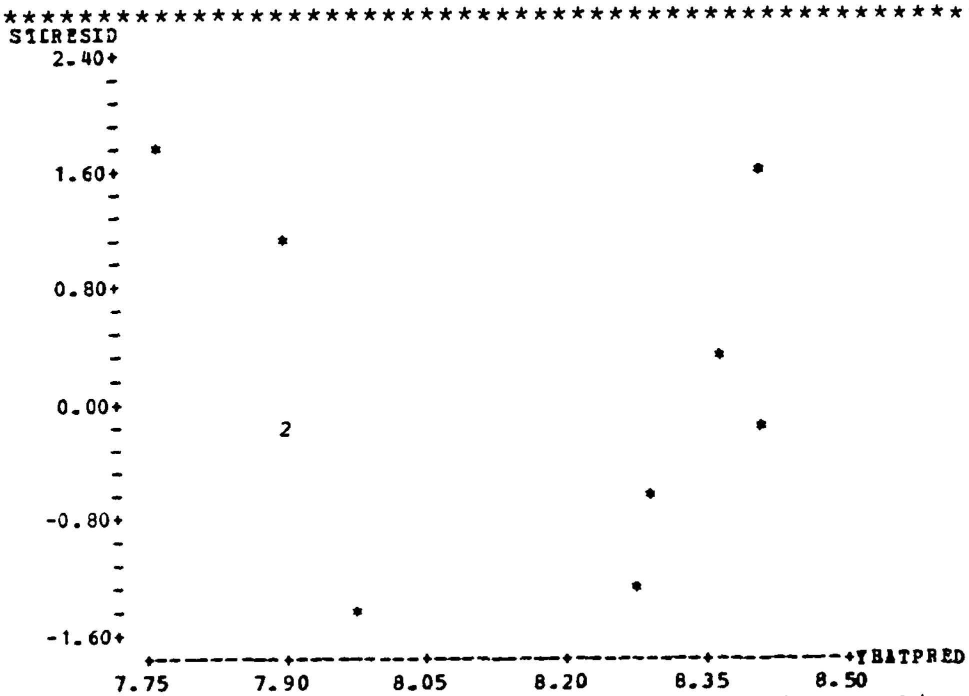

Figure 59: Heating Peak for Raleigh, North Carolina

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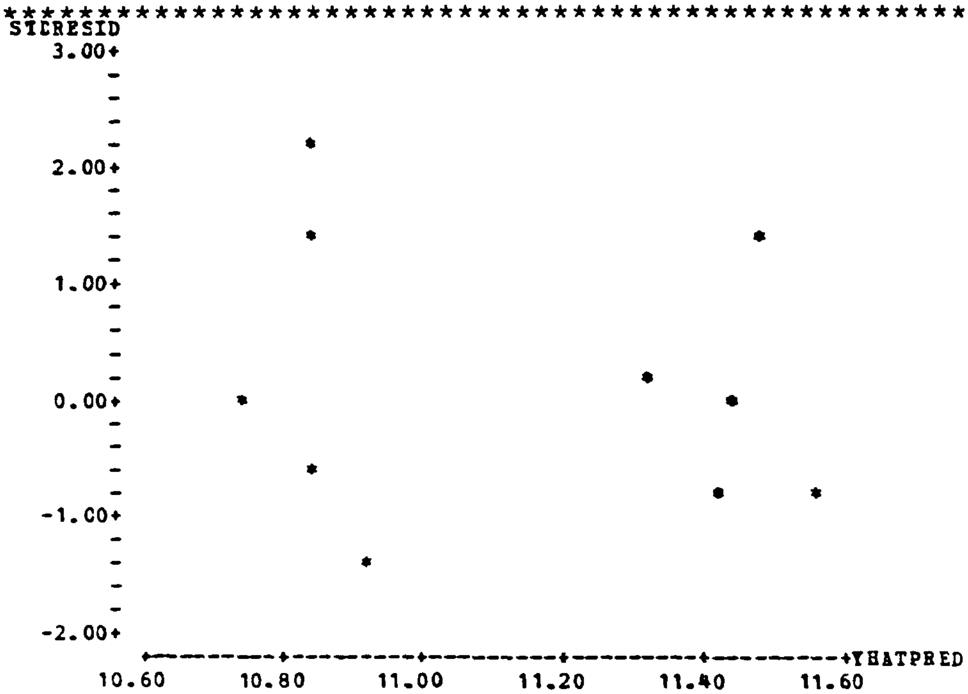

Figure 60: Heating Peak for Portland, Maine

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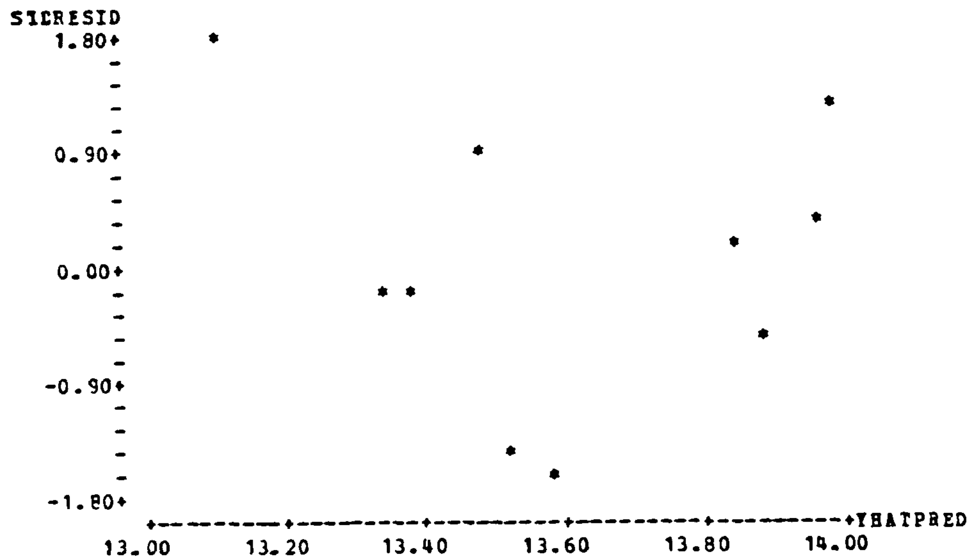

Figure 61: Heating Peak for Minneapolis, Minnesota

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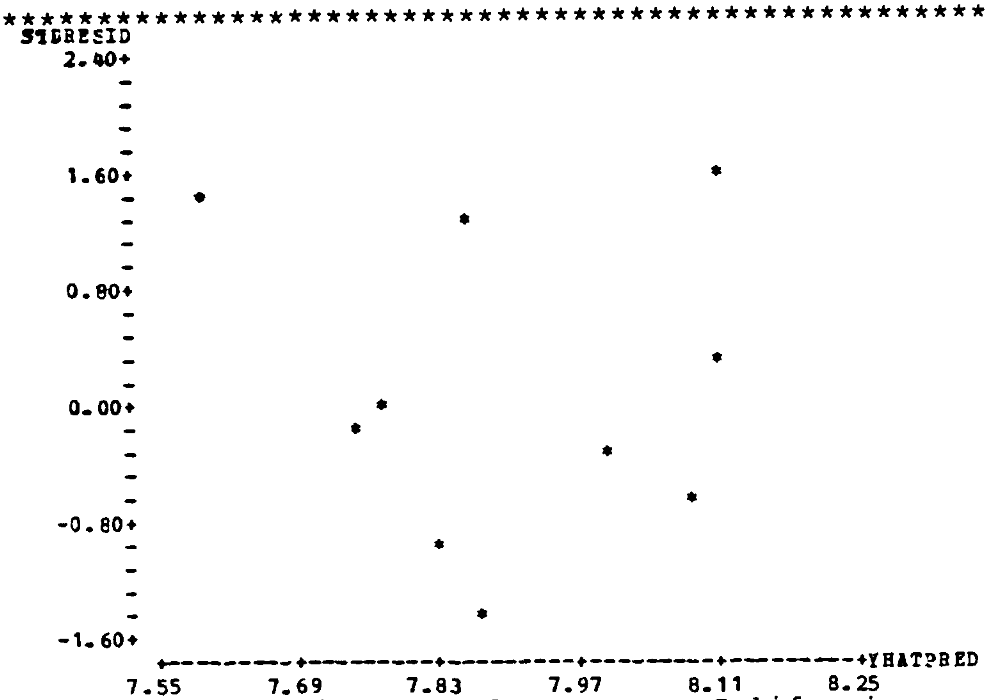

Figure 62: Heating Peak for Fresno, California

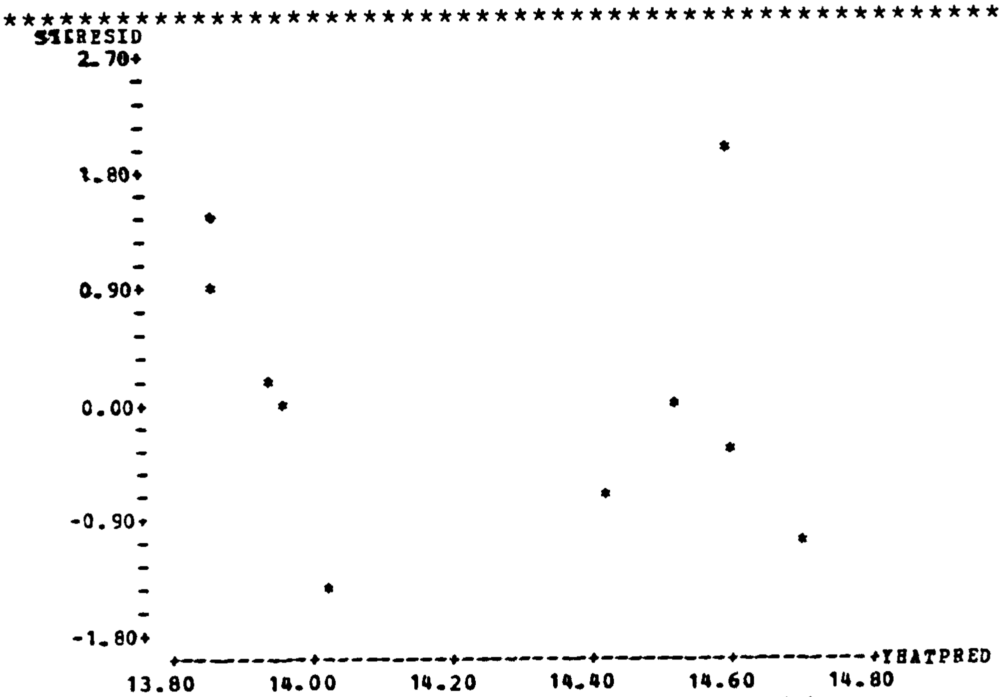

Figure 63: Heating Peak for Cleveland, Ohio

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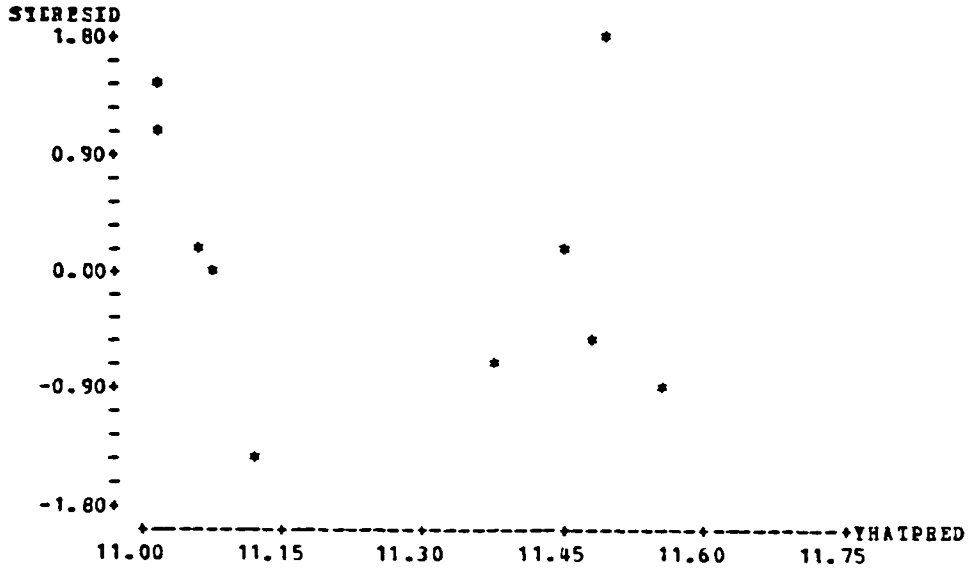

Figure 64: Heating Peak for Boise, Idaho

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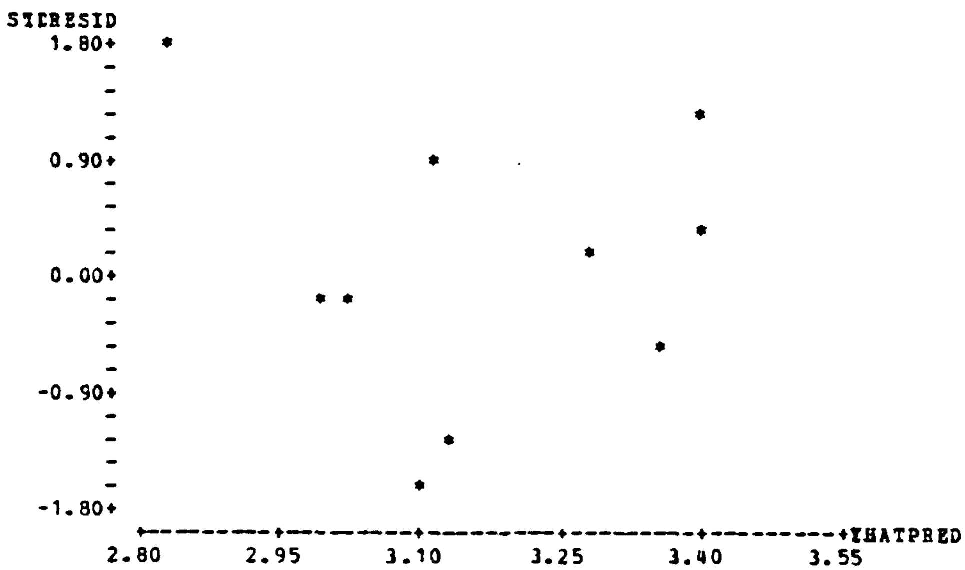

Figure 65: Heating Peak for Phoenix, Arizona

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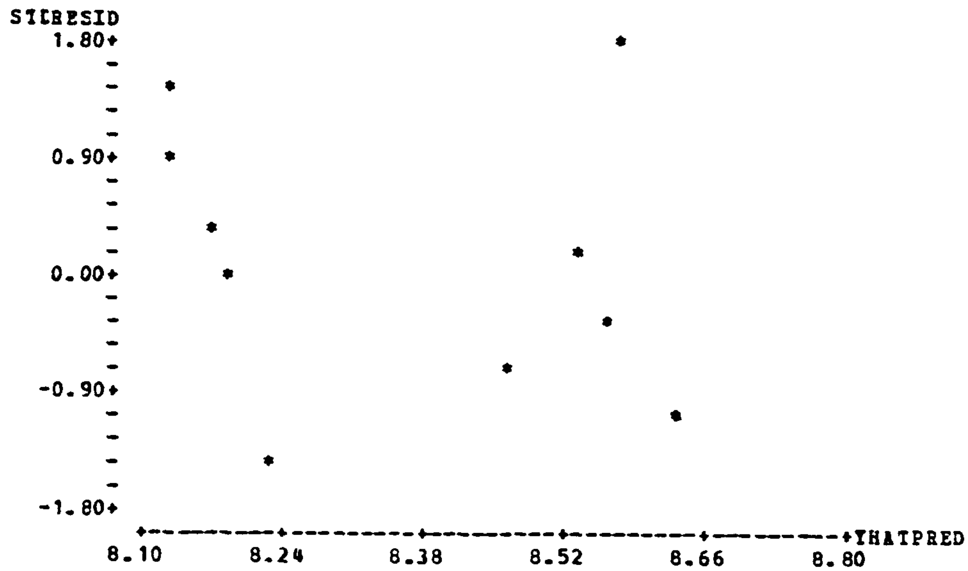

Figure 66: Heating Peak for Tulsa, Oklahoma

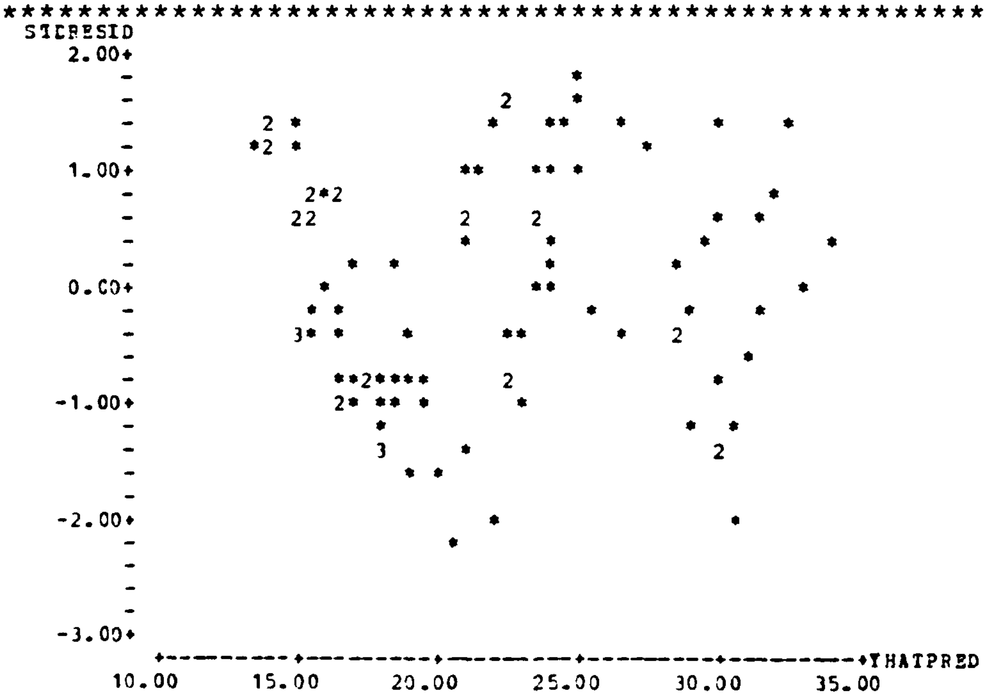

Figure 67: Climate Generalized Cooling Load Residual Plot

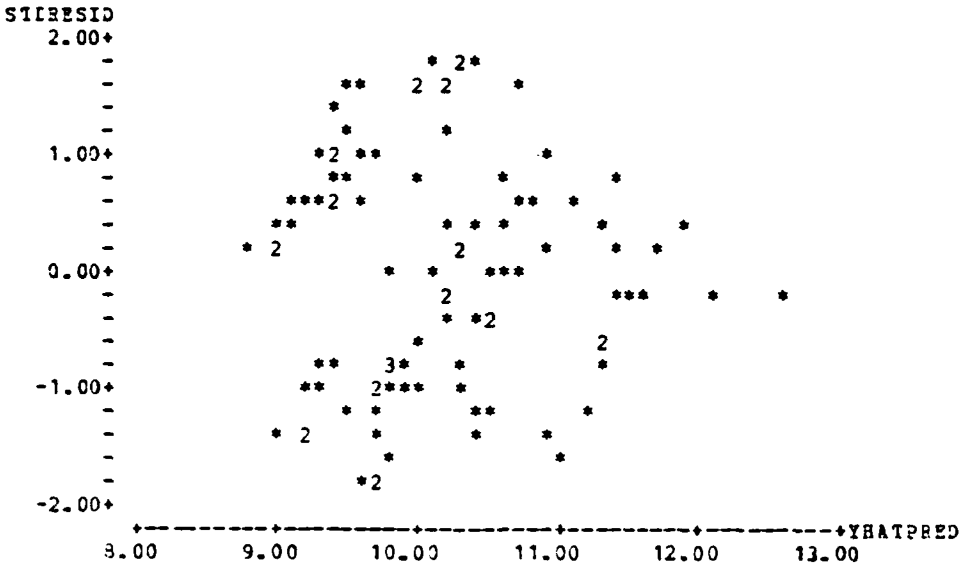

Figure 68: Climate Generalized Cooling Peak Residual Plot

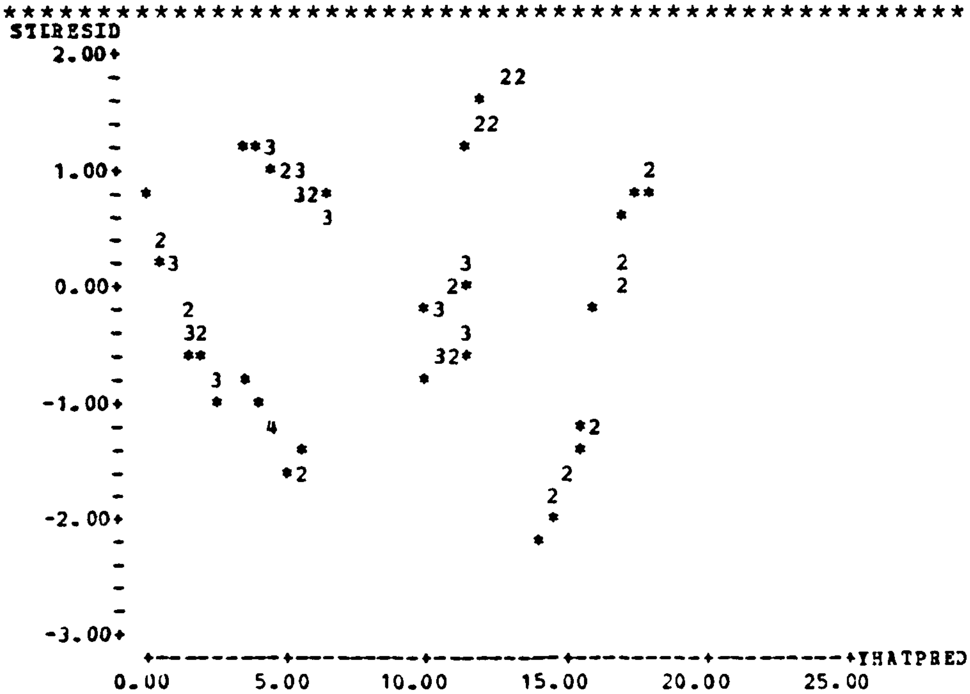

Figure 69: Climate Generalized Heating Load Residual Plot

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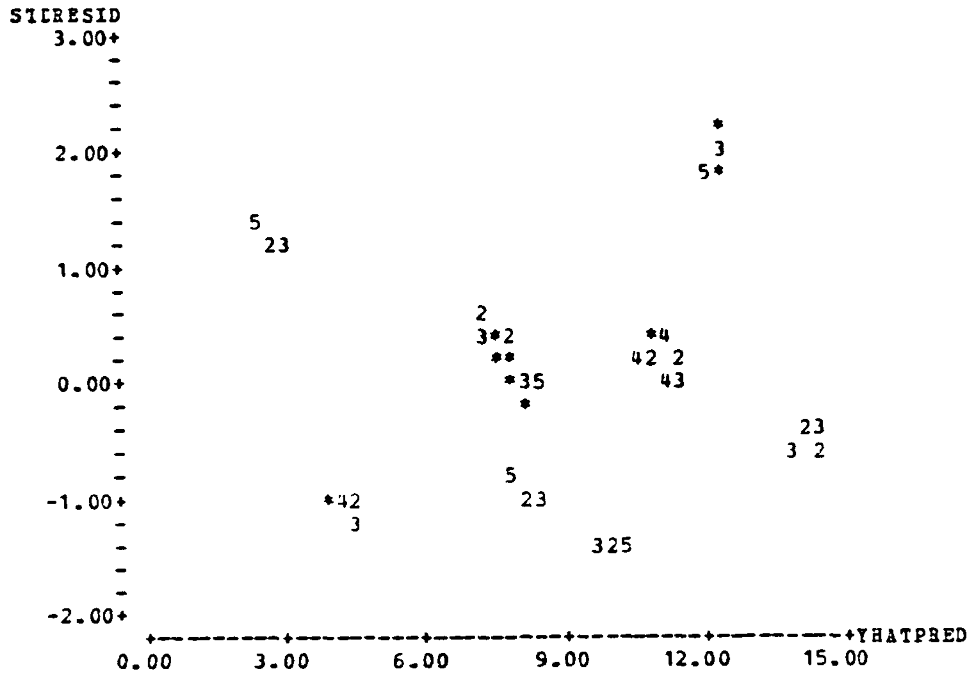

<u>Figure 70</u>: Climate Generalized Heating Peak Residual Plot

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Appendix C

LIFE-CYCLE COST ANALYSIS RESULTS AND ENERGY RATES

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Table 15: Fuel Prices and Escalation Rates: Portland, Me.

1984 Average Fuel Prices (1)

Fuel Type	Electricity	Dist.Fuel	Natural Gas	Steam Coal
$/Mil Btu	25.08	6.89	6.60	2.99

Projected Average Fuel Price Escalation Rates
(Percentage Change Compounded Annually)

Period	1985-1990	1990-1995	1995-2010
Fuel (1)			
Elect	.0324	.0059	.0059
Dist	.0557	.0556	.0391
Gas	.0567	.0740	.0391
Steam	.0231	.0329	.0329

(1) Assume the following Btu content per sales unit of energy: 3,412 Btu/kWh of electricity; 138,690 Btu/gal of distillate; 1,016 Btu/cu.ft. of natural gas; 22,500,000 Btu/ton of steam coal.

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Table 16: Fuel Prices and Escalation Rates: Raleigh, N.C. and Tampa, Fl.

1984 Average Fuel Prices (1)

Fuel Type	Electricity	Dist.Fuel	Natural Gas	Steam Coal
$/Mil Btu	18.69	6.07	5.36	2.08

Projected Average Fuel Price Escalation Rates
(Percentage Change Compounded Annually)

Period	1985-1990	1990-1995	1995-2010
Fuel (1)			
Elect	.0000	-.0054	-.0054
Dist	.0627	.0611	.0391
Gas	.0574	.0934	.0391
Steam	.0133	.0252	.0252

(1) Assume the following Btu content per sales unit of energy: 3,412 Btu/kWh of electricity; 138,690 Btu/gal of distillate; 1,016 Btu/cu.ft. of natural gas; 22,500,000 Btu/ton of steam coal.

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Table 17: Fuel Prices and Escalation Rates: Minneapolis, Mn. and Cleveland, Oh.

1984 Average Fuel Prices (1)

Fuel Type	Electricity	Dist.Fuel	Natural Gas	Steam Coal
$/Mil Btu	20.59	6.11	5.47	2.23

Projected Average Fuel Price Escalation Rates
(Percentage Change Compounded Annually)

Period	1985-1990	1990-1995	1995-2010
Fuel (1)			
Elect	.0045	-.0174	-.0174
Dist	.0623	.0608	.0391
Gas	.0409	.0774	.0391
Steam	.0108	.0264	.0264

(1) Assume the following Btu content per sales unit of energy: 3,412 Btu/kWh of electricity; 138,690 Btu/gal of distillate; 1,016 Btu/cu.ft. of natural gas; 22,500,000 Btu/ton of steam coal.

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Table 18: Fuel Prices and Escalation Rates: Tulsa, Ok.

1984 Average Fuel Prices (1)

Fuel Type	Electricity	Dist.Fuel	Natural Gas	Steam Coal
$/Mil Btu	19.25	5.76	5.03	2.13

Projected Average Fuel Price Escalation Rates
(Percentage Change Compounded Annually)

Period	1985-1990	1990-1995	1995-2010
Fuel (1)			
Elect	.0067	.0255	.0255
Dist	.0658	.0634	.0391
Gas	.0444	.0888	.0391
Steam	.0158	.0262	.0262

(1) Assume the following Btu content per sales unit of energy: 3,412 Btu/kWh of electricity; 138,690 Btu/gal of distillate; 1,016 Btu/cu.ft. of natural gas; 22,500,000 Btu/ton of steam coal.

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Table 19: Fuel Prices and Escalation Rates: Phoenix, Az. and Fresno, Ca.

1984 Average Fuel Prices (1)

Fuel Type	Electricity	Dist.Fuel	Natural Gas	Steam Coal
$/Mil Btu	19.11	5.83	6.23	2.30

Projected Average Fuel Price Escalation Rates
(Percentage Change Compounded Annually)

Period	1985-1990	1990-1995	1995-2010
Fuel (1)			
Elect	-.0008	.0366	.0336
Dist	.0652	.0632	.0391
Gas	.0413	.0659	.0391
Steam	.0130	.0336	.0336

(1) Assume the following Btu content per sales unit of energy: 3,412 Btu/kWh of electricity; 138,690 Btu/gal of distillate; 1,016 Btu/cu.ft. of natural gas; 22,500,000 Btu/ ton of steam coal.

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Table 20: Fuel Prices and Escalation Rates: Boise, Id. and Seattle, Wa.

1984 Average Fuel Prices (1)

Fuel Type	Electricity	Dist.Fuel	Natural Gas	Steam Coal
$/Mil Btu	10.09	6.27	7.06	2.60

Projected Average Fuel Price Escalation Rates
(Percentage Change Compounded Annually)

Period	1985-1990	1990-1995	1995-2010
Fuel (1)			
Elect	-.0076	.0355	.0355
Dist	.0610	.0600	.0391
Gas	.0333	.0554	.0391
Steam	.0167	.0312	.0312

(1) Assume the following Btu content per sales unit of energy: 3,412 Btu/kWh of electricity; 138,690 Btu/gal of distillate; 1,016 Btu/cu.ft. of natural gas; 22,500,000 Btu/ton of steam coal.

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Table 34: Total Life-Cycle Costs for Portland, Maine

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	201.98	448.48	283.60	344.93	320.17
DBLGLS	177.74	384.08	261.45	307.06	288.64
TNTCLE	180.28	388.38	257.42	306.13	286.46
LOECLE	171.70	366.23	255.74	296.83	280.24
LOETNT	173.91	369.70	251.71	295.60	277.88
HTMCLE	176.83	372.50	253.16	297.55	279.62
HTMTNT	181.50	379.20	254.62	300.96	282.25
LORTNT	194.41	403.13	265.42	316.64	295.96
HIRTNT	193.94	402.08	263.67	315.15	294.36
GLDCLE	186.69	382.62	258.17	304.46	297.11
SILCLE	189.31	395.49	259.34	309.98	289.53
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 33: Total Life-Cycle Costs for Raleigh, North Carolina

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
.sp (3)	(1)	(1)	(1)	(1)	(1)
SINGLS	102.34	218.78	175.18	217.91	203.30
DBLGLS	99.65	203.17	171.73	202.54	192.01
TNTCLE	98.76	199.96	165.77	199.31	187.85
LOECLE	99.61	198.96	170.78	198.39	188.95
LOETNT	98.85	195.97	165.28	195.35	185.07
HTMCLE	101.23	197.63	166.43	197.00	186.55
HTMTNT	103.51	199.10	166.16	198.44	187.41
LORTNT	109.90	208.33	171.62	207.59	195.30
HIRTNT	109.12	206.65	169.58	205.90	193.49
GLDCLE	108.83	202.91	169.81	202.24	191.16
SILCLE	105.62	202.63	166.21	201.89	189.70
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 32: Total Life-Cycle Costs for Seattle, Washington

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	145.41	156.52	149.41	209.00	185.27
DBLGLS	132.53	141.99	136.75	180.71	163.20
TNTCLE	134.93	144.49	138.87	185.94	167.19
LOECLE	130.61	139.64	134.88	174.83	158.92
LOETNT	132.83	141.94	136.84	179.61	162.58
HTMCLE	135.93	145.05	139.88	183.20	165.95
HTMTNT	140.22	149.44	144.04	189.30	171.28
LORTNT	149.49	159.12	153.19	202.89	183.10
HIRTNT	149.39	159.01	153.04	203.07	183.15
GLDCLE	146.27	155.45	150.04	195.39	177.33
SILCLE	145.41	154.96	149.08	198.35	178.73

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 31: Total Life-Cycle Costs for Tampa, Florida

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	95.54	204.24	196.86	204.09	201.62
DBLGLS	97.62	198.81	193.87	198.71	197.06
TNTCLE	93.96	189.75	184.12	189.64	187.75
LOECLE	98.41	196.39	191.95	196.30	194.81
LOETNT	95.17	188.11	183.07	188.01	186.32
HTMCLE	96.94	188.46	183.26	188.36	186.62
HTMTNT	97.67	186.60	180.91	186.49	184.58
LORTNT	102.23	191.93	185.47	191.81	189.64
HIRTNT	100.84	188.97	182.31	188.83	186.60
GLDCLE	102.31	188.97	183.09	188.85	186.88
SILCLE	97.66	185.61	179.09	185.48	183.29
******	*****	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 30: Present Value Energy Costs for Tulsa, Oklahoma

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	115.18	298.92	225.19	269.86	246.22
DBLGLS	100.51	260.86	207.63	239.87	222.81
TNTCLE	98.50	255.65	198.22	233.01	214.76
LOECLE	96.04	249.26	201.24	230.33	214.94
LOETNT	94.10	244.23	192.39	223.79	207.18
HTMCLE	93.43	242.47	189.90	221.75	204.89
HTMTNT	92.74	240.68	185.49	218.92	201.23
LORTNT	95.18	248.65	187.62	224.59	205.03
HIRTNT	94.91	246.33	184.81	222.08	202.36
GLDCLE	91.24	236.79	181.40	214.95	197.20
SILCLE	94.35	244.87	184.35	221.02	201.62
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 29: Present Value Energy Costs for Phoenix, Arizona

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	112.73	269.76	252.13	260.51	257.32
DBLGLS	103.86	248.53	235.96	241.61	239.45
TNTCLE	98.92	236.37	222.39	228.90	226.42
LOECLE	99.92	239.12	228.18	232.96	231.14
LOETNT	95.11	227.60	215.48	220.99	218.89
HTMCLE	93.73	224.30	211.91	217.60	215.43
HTMTNT	91.45	218.84	205.39	211.70	209.30
LORTNT	93.13	222.85	207.21	214.75	211.88
HIRTNT	91.66	219.33	203.31	211.08	208.12
GLDCLE	89.21	213.47	199.75	206.25	203.78
SILCLE	91.32	218.52	202.89	210.45	207.57
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 28: Present Value Energy Costs for Boise, Idaho

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	152.75	164.41	157.76	213.54	191.33
DBLGLS	130.88	140.87	135.89	177.71	161.06
TNTCLE	130.52	140.50	135.16	179.89	162.07
LOECLE	124.28	133.78	129.26	213.54	152.03
LOETNT	123.82	133.28	128.45	168.93	152.81
HTMCLE	123.47	132.91	128.02	169.00	152.68
HTMTNT	123.98	133.45	128.34	171.18	154.12
LORTNT	129.60	139.50	133.87	181.07	162.27
HIRTNT	129.02	138.87	133.21	180.72	161.80
GLDCLE	122.70	132.07	126.95	169.85	152.77
SILCLE	128.01	137.79	132.21	178.97	160.35
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 27: Present Value Energy Costs for Cleveland, Ohio

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	149.16	315.27	203.59	302.56	250.27
DBLGLS	123.48	260.98	178.30	251.57	212.85
TNTCLE	123.97	262.02	175.01	252.12	211.37
LOECLE	116.51	246.26	171.13	237.71	202.53
LOETNT	116.81	246.89	167.85	237.89	200.88
HTMCLE	116.57	246.39	166.73	237.32	200.02
HTMTNT	117.30	247.91	165.57	238.54	199.98
LORTNT	123.34	260.68	170.65	250.44	208.27
HIRTNT	122.71	259.36	169.19	249.10	206.88
GLDCLE	115.95	245.06	163.14	235.74	197.38
SILCLE	121.64	257.09	168.25	246.99	205.38
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 26: Present Value Energy Costs for Fresno, California

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	108.81	257.66	222.85	244.63	235.05
DBLGLS	99.26	235.05	210.86	226.58	219.33
TNTCLE	96.07	227.49	200.85	217.65	209.91
LOECLE	95.65	226.49	205.52	219.39	212.87
LOETNT	92.57	219.21	195.69	210.88	203.93
HTMCLE	91.68	217.09	193.02	208.49	201.45
HTMTNT	90.40	214.07	188.12	204.59	192.21
LORTNT	92.51	219.06	189.21	207.86	199.66
HIRTNT	91.51	216.70	186.38	205.27	197.00
GLDCLE	88.80	210.23	184.00	200.58	193.19
SILCLE	91.11	215.75	186.09	204.61	196.48
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 25: Present Value Energy Costs for Minneapolis, Minnesota

Glazing Systems *******	Heating Energy Type Steam(2) *****	Electric ********	Steam *****	Oil ***	Gas ***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	175.96	371.91	231.37	355.92	290.11
DBLGLS	143.09	302.44	198.00	290.56	241.65
TNTCLE	144.24	304.85	195.30	292.39	241.09
LOECLE	133.75	282.68	188.17	271.93	227.67
LOETNT	134.68	284.66	185.47	273.38	226.93
HTMCLE	134.47	284.22	184.36	272.86	226.09
HTMTNT	135.61	286.63	183.59	274.91	226.66
LORTNT	143.69	303.70	190.90	290.87	238.05
HIRTNT	142.90	302.02	189.22	289.19	236.36
GLDCLE	133.89	282.99	180.71	271.35	223.45
SILCLE	141.47	299.02	187.90	286.37	234.34
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 24: Present Value Energy Costs for Portland, Maine

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	201.98	448.48	283.60	344.93	320.17
DBLGLS	169.07	375.42	252.78	298.39	279.97
TNTCLE	170.51	378.62	247.65	296.36	276.69
LOECLE	159.40	353.93	243.44	284.53	267.94
LOETNT	160.43	356.22	238.22	282.11	264.39
HTMCLE	160.33	356.00	236.66	281.05	263.12
HTMTNT	162.00	359.70	235.12	281.46	262.75
LORTNT	171.02	379.74	242.03	293.25	272.57
HIRTNT	170.55	378.69	240.22	291.76	270.97
GLDCLE	160.54	356.48	232.03	278.32	270.97
SILCLE	168.94	375.13	238.97	289.62	269.17
******	*****	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 23: Present Value Energy Costs for Raleigh, North Carolina

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	102.34	218.78	175.18	217.91	203.30
DBLGLS	90.99	194.50	163.06	193.87	183.34
TNTCLE	88.99	190.23	156.00	189.54	178.08
LOECLE	87.31	186.65	158.47	186.09	176.65
LOETNT	85.36	182.48	151.79	181.87	171.59
HTMCLE	84.73	181.13	149.93	180.50	170.05
HTMTNT	84.01	179.60	146.66	178.94	167.91
LORTNT	86.51	184.94	148.23	184.20	171.90
HIRTNT	85.72	183.26	146.19	182.51	170.09
GLDCLE	82.69	176.77	143.66	176.10	165.01
SILCLE	85.26	182.26	145.84	181.53	169.33
******	*****	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 22: Present Value Energy Costs for Seattle, Washington

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	145.41	156.52	149.41	209.00	185.27
DBLGLS	123.86	133.33	128.08	172.04	154.53
TNTCLE	125.16	134.72	129.10	176.17	157.42
LOECLE	118.31	127.34	122.58	162.53	146.62
LOETNT	119.34	128.46	123.36	166.13	149.10
HTMCLE	119.43	128.55	123.38	166.70	149.45
HTMTNT	120.72	129.94	124.54	169.80	151.78
LORTNT	126.10	135.73	129.80	179.49	159.70
HIRTNT	126.00	135.62	129.65	179.68	159.76
GLDCLE	120.13	129.30	123.89	169.25	151.19
SILCLE	125.04	134.59	128.72	177.98	158.36
******	*****	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 21: Present Value Energy Costs for Tampa, Florida

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	95.54	204.24	196.86	204.09	201.62
DBLGLS	88.95	190.14	185.20	190.05	188.39
TNTCLE	84.19	179.98	174.35	179.87	177.98
LOECLE	86.11	184.09	179.65	184.00	182.51
LOETNT	81.69	174.63	169.59	174.53	172.84
HTMCLE	80.44	171.96	166.76	171.86	170.12
HTMTNT	78.17	167.10	161.41	166.99	165.08
LORTNT	78.84	168.54	162.08	168.42	166.25
HIRTNT	77.45	165.57	158.91	165.44	163.21
GLDCLE	76.17	162.83	156.94	162.71	160.74
SILCLE	77.30	165.25	158.72	165.12	162.93
******	*****	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 35: Total Life-Cycle Costs for Minneapolis, Minnesota

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	175.96	371.91	231.37	355.92	290.11
DBLGLS	151.76	311.11	206.67	299.22	250.32
TNTCLE	154.01	314.62	205.07	302.16	250.86
LOECLE	146.05	294.98	200.47	284.23	239.97
LOETNT	148.17	298.14	198.96	286.86	240.41
HTMCLE	150.97	300.72	200.86	289.36	242.59
HTMTNT	155.11	306.13	203.09	294.41	246.16
LORTNT	167.08	327.10	214.29	314.26	261.44
HIRTNT	166.29	325.41	212.61	312.58	259.76
GLDCLE	160.03	309.13	206.85	297.50	249.60
SILCLE	161.84	319.38	208.26	306.74	254.70
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List o' Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 36: Total Life-Cycle Costs for Fresno, California

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	108.81	257.66	222.85	244.63	235.05
DBLGLS	107.93	243.72	219.53	235.25	228.00
TNTCLE	105.84	237.26	210.20	227.41	219.68
LOECLE	107.95	238.79	217.82	231.69	225.17
LOETNT	106.06	232.70	209.18	224.37	217.42
HTMCLE	108.18	233.59	209.52	224.99	217.95
HTMTNT	109.90	233.57	207.62	224.09	216.71
LORTNT	115.90	242.45	212.60	231.25	223.05
HIRTNT	114.90	240.09	209.77	228.66	220.39
GLDCLE	114.94	236.38	210.15	226.73	219.33
SILCLE	111.47	236.11	206.46	224.97	216.85
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 37: Total Life-Cycle Costs for Cleveland, Ohio

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	149.16	315.27	203.59	302.56	250.27
DBLGLS	132.15	269.65	186.96	260.24	221.52
TNTCLE	133.74	271.79	184.78	261.89	221.14
LOECLE	128.81	258.56	183.43	250.01	214.83
LOETNT	130.29	260.37	181.33	251.38	214.37
HTMCLE	133.07	262.89	183.23	253.82	216.52
HTMTNT	136.80	267.41	185.07	258.04	219.48
LORTNT	146.73	284.07	194.04	273.83	231.67
HIRTNT	146.10	282.76	192.58	272.50	230.27
GLDCLE	142.09	271.21	189.28	261.89	223.52
SILCLE	142.00	277.46	188.62	267.35	225.75
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 38: Total Life-Cycle Costs for Boise, Idaho

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	152.75	164.41	157.76	213.54	191.33
DBLGLS	139.54	149.54	144.55	186.38	169.73
TNTCLE	140.29	150.26	144.93	189.66	171.84
LOECLE	136.58	146.08	141.56	179.41	164.34
LOETNT	137.30	146.76	141.93	182.41	166.29
HTMCLE	139.97	149.41	144.52	185.50	169.18
HTMTNT	143.48	152.95	147.84	190.68	173.62
LORTNT	152.99	162.89	157.26	204.46	185.66
HIRTNT	152.41	162.27	156.60	204.11	185.19
GLDCLE	148.84	158.21	153.09	195.99	178.91
SILCLE	148.38	158.15	152.58	199.34	180.72

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 39: Total Life-Cycle Costs for Phoenix, Arizona

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	112.73	269.76	252.13	260.51	257.32
DBLGLS	112.53	257.20	244.63	250.28	248.12
TNTCLE	108.68	246.14	232.16	238.67	236.19
LOECLE	112.23	251.42	240.48	245.26	243.44
LOETNT	108.60	241.08	228.96	234.48	232.38
HTMCLE	110.23	240.80	228.41	234.10	231.93
HTMTNT	110.95	238.34	224.89	231.20	228.80
LORTNT	116.52	246.25	230.60	238.14	235.27
HIRTNT	115.05	242.72	226.71	234.47	231.52
GLDCLE	115.35	239.61	225.90	232.40	229.92
SILCLE	111.68	238.89	223.26	230.81	227.93
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 40: Total Life-Cycle Costs for Tulsa, Oklahoma

Glazing Systems	Heating Energy Type Steam(2)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(3)	(1)	(1)	(1)	(1)	(1)
SINGLS	115.18	298.92	225.19	269.86	246.22
DBLGLS	109.18	269.52	216.30	248.54	231.48
TNTCLE	108.27	265.42	207.99	242.78	224.53
LOECLE	108.34	261.57	213.54	242.64	227.24
LOETNT	107.59	257.71	205.88	237.28	220.66
HTMCLE	109.93	258.97	206.40	238.25	221.39
HTMTNT	112.24	260.18	204.99	238.42	220.73
LORTNT	119.20	272.04	211.01	247.98	228.42
HIRTNT	118.31	269.73	208.20	245.47	225.75
GLDCLE	117.38	262.93	207.54	241.10	223.34
SILCLE	114.72	265.24	204.72	241.38	221.98
******	******	******	******	******	******

Notes:

(1) Amounts below are in thousands of dollars
(2) Represents absorption chiller cooling and steam heat
(3) Systems below are insulated units except for SINGLS
Refer to the List of Symbols for specific definitions
SINGLS = Single lite clear glass
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 41: Savings-to-Investment Ratios for Tampa, Florida

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	.76	1.63	1.35	1.62	1.53
TNTCLE	1.16	2.48	2.30	2.48	2.42
LOECLE	.77	1.64	1.40	1.63	1.55
LOETNT	1.03	2.20	2.02	2.19	2.13
HTMCLE	.92	1.96	1.82	1.95	1.91
HTMTNT	.89	1.91	1.82	1.90	1.87
LORTNT	.71	1.53	1.49	1.53	1.51
HIRTNT	.77	1.65	1.62	1.65	1.64
GLDCLE	.74	1.58	1.53	1.58	1.56
SILCLE	.90	1.92	1.87	1.91	1.90
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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<u>Table 42</u>: Savings-to-Investment Ratios for Seattle, Washington

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	2.49	2.68	2.46	4.26	3.55
TNTCLE	2.07	2.23	2.08	3.36	2.85
LOECLE	2.20	2.37	2.18	3.78	3.14
LOETNT	1.93	2.08	1.93	3.18	2.68
HTMCLE	1.58	1.70	1.58	2.56	2.17
HTMTNT	1.27	1.36	1.28	2.01	1.72
LORTNT	.83	.86	.84	1.26	1.09
HIRTNT	.83	.89	.85	1.25	1.09
GLDCLE	.97	1.04	.98	1.52	1.30
SILCLE	1.00	1.08	1.02	1.52	1.32
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 43: Savings-to-Investment Ratios for Raleigh, North Carolina

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	1.31	2.80	1.40	2.77	2.30
TNTCLE	1.37	2.94	1.96	2.90	2.58
LOECLE	1.22	2.61	1.36	2.59	2.17
LOETNT	1.26	2.69	1.73	2.67	2.35
HTMCLE	1.07	2.28	1.53	2.27	2.02
HTMTNT	.94	2.01	1.46	2.00	1.82
LORTNT	.68	1.45	1.15	1.44	1.34
HIRTNT	.71	1.52	1.24	1.51	1.42
GLDCLE	.75	1.61	1.21	1.60	1.47
SILCLE	.84	1.79	1.44	1.79	1.67
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 44: Savings-to-Investment Ratios for Portland, Maine

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	3.80	8.43	3.56	5.37	4.64
TNTCLE	3.22	7.15	3.68	4.97	4.45
LOECLE	3.46	7.69	3.27	4.91	4.25
LOETNT	3.08	6.84	3.37	4.66	4.14
HTMCLE	2.52	5.61	2.85	3.87	3.46
HTMTNT	2.05	4.55	2.49	3.26	2.94
LORTNT	1.32	2.94	1.78	2.21	2.04
HIRTNT	1.34	2.98	1.85	2.27	2.10
GLDCLE	1.59	3.52	1.97	2.55	1.88
SILCLE	1.62	3.60	2.19	2.72	2.50
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of *Symbols for specific definitions*
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 45: Savings-to-Investment Ratios for Minneapolis, Minnesota

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	3.79	8.01	3.85	7.54	5.59
TNTCLE	3.25	6.86	3.69	6.50	5.02
LOECLE	3.43	7.25	3.51	6.83	5.08
LOETNT	3.06	6.47	3.40	6.12	4.69
HTMCLE	2.52	5.31	2.85	5.03	3.88
HTMTNT	2.07	4.37	2.45	4.16	3.26
LORTNT	1.38	2.92	1.73	2.78	2.23
HIRTNT	1.41	2.99	1.80	2.85	2.30
GLDCLE	1.61	3.40	1.94	3.24	2.55
SILCLE	1.69	3.57	2.14	3.42	2.74
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 46: Savings-to-Investment Ratios for Fresno, California

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	1.10	2.61	1.38	2.08	1.81
TNTCLE	1.30	3.09	2.30	2.76	2.57
LOECLE	1.07	2.53	1.41	2.05	1.80
LOETNT	1.20	2.85	2.01	2.50	2.31
HTMCLE	1.04	2.46	1.81	2.19	2.04
HTMTNT	.94	2.24	1.78	2.05	1.94
LORTNT	.70	1.65	1.44	1.57	1.51
HIRTNT	.74	1.75	1.56	1.68	1.63
GLDCLE	.77	1.81	1.49	1.69	1.60
SILCLE	.87	2.06	1.81	1.97	1.89
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 47: Savings-to-Investment Ratios for Cleveland, Ohio

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	2.96	6.26	2.92	5.88	4.32
TNTCLE	2.58	5.45	2.93	5.16	3.98
LOECLE	2.65	5.61	2.64	5.27	3.88
LOETNT	2.40	5.07	2.65	4.80	3.66
HTMCLE	1.98	4.18	2.23	3.95	3.05
HTMTNT	1.63	3.45	1.95	3.28	2.58
LORTNT	1.10	2.33	1.41	2.23	1.80
HIRTNT	1.13	2.39	1.47	2.29	1.86
GLDCLE	1.27	2.69	1.55	2.56	2.02
SILCLE	1.35	2.86	1.74	2.73	2.20
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 48: Savings-to-Investment Ratios for Boise, Idaho

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	2.52	2.72	2.52	4.13	3.49
TNTCLE	2.28	2.45	2.31	3.45	2.99
LOECLE	2.31	2.49	2.32	3.78	3.19
LOETNT	2.15	2.31	2.17	3.31	2.86
HTMCLE	1.77	1.91	1.80	2.70	2.34
HTMTNT	1.48	1.59	1.51	2.17	1.91
LORTNT	.99	1.07	1.02	1.39	1.24
HIRTNT	1.01	1.09	1.05	1.40	1.26
GLDCLE	1.15	1.24	1.18	1.67	1.48
SILCLE	1.22	1.31	1.26	1.70	1.52
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 49: Savings-to-Investment Ratios for Phoenix, Arizona

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
(2)					
DBLGLS	1.02	2.45	1.87	2.18	2.06
TNTCLE	1.41	3.42	3.05	3.24	3.16
LOECLE	1.04	2.49	1.95	2.24	2.13
LOETNT	1.31	3.13	2.72	2.93	2.85
HTMCLE	1.15	2.76	2.44	2.60	2.54
HTMTNT	1.09	2.61	2.40	2.50	2.46
LORTNT	.84	2.01	1.92	1.96	1.94
HIRTNT	.90	2.16	2.09	2.11	2.10
GLDCLE	.90	2.15	2.00	2.08	2.05
SILCLE	1.05	2.52	2.42	2.46	2.44

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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Table 50: Savings-to-Investment Ratios for Tulsa, Oklahoma

Glazing Systems	Heating Energy Type Steam(1)	Electric	Steam	Oil	Gas
*******	*****	********	*****	***	***
(2)					
DBLGLS	1.69	4.39	2.03	3.46	2.70
TNTCLE	1.71	4.43	2.76	3.77	3.22
LOECLE	1.56	4.04	1.95	3.21	2.54
LOETNT	1.56	4.06	2.43	3.42	2.90
HTMCLE	1.32	3.42	2.14	2.92	2.51
HTMTNT	1.15	2.99	2.04	2.61	2.31
LORTNT	.82	2.15	1.61	1.94	1.76
HIRTNT	.87	2.25	1.73	2.04	1.88
GLDCLE	.92	2.38	1.68	2.10	1.88
SILCLE	1.02	2.65	2.01	2.40	2.19
******	****	****	****	****	****

Notes:

(1) Represents absorption chiller cooling and steam heat
(2) Systems below are all sealed insulated units
Refer to the List of Symbols for specific definitions
DBLGLS = Two clear glass lites
TNTCLE = Tinted outside lite-clear inside lite
LOECLE = Clear outside lite-low emissivity inside lite
LOETNT = Tinted outside lite-low emissivity inside lite
HTMCLE = Low emissivity film between two clear lites
HTMTNT = Low emissivity film between tinted-clear lites
LORTNT = Low reflective tinted out-clear inside lite
HIRTHT = High reflective tinted out-clear inside lite
GLDCLE = High reflective gold outside-both clear lites
SILCLE = High reflective silver out-both clear lites

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